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ICEBREAKER MIDBODY RESISTANCE
PHASE III

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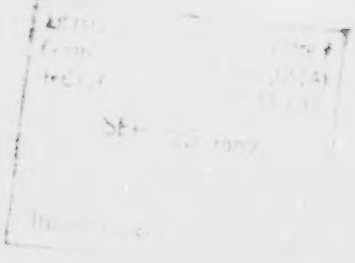
Authors:

D.N. Baker
T. Orendorff
J. Hartleib

From:

Melville Shipping Ltd.
Suite 1007
350 Sparks Street
Ottawa, Ontario
K1R 7S8



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PROJECT TEAM

The Project Team comprised:

D. Baker
T. Orendorff
J. Hartleib
D. Bradley

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Un sommaire en français de ce rapport est inclus avant la Table des matières.

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16. Abstract

This report describes the third phase of work related to the analysis of length and beam effects on icebreaking performance.

The objective of this work was to evaluate the parametric influence of length (L), breadth (B), L/B ratio and bow form on the resistance of a hull form in ice.

The project was conducted in two parts. The first part reviewed the tests at model scale and compared the new analysis approach to previous work. Relationships between resistance and friction were also established for use later in the work. The second part of the project scaled each model to a displacement of 30 000 t. This was accomplished by using target ice thickness and strength that, in association with the appropriate scale ratio, resulted in a ship of 30 000 t in 1 m thick, 500 kPa ice.

The difference between the resistances found in varying the breadth of a candidate bow, as revealed in the beam variation phase of this project, were explained in semi-quantitative terms.

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16. Résumé

Ce rapport décrit les travaux de la phase III de la recherche portant sur l'influence du bau et de la longueur de la section médiane d'une coque sur les performances d'un brise-glace.

La phase III avait pour objectif d'analyser « paramétriquement » l'influence de la longueur (L), du bau (B), du rapport L/B et de la forme géométrique de la proue sur la tenue à l'action des glaces d'une coque de forme donnée.

L'analyse a été menée en deux étapes. Dans la première étape, les chercheurs ont procédé à l'examen des résultats antérieurs et à leur comparaison avec ceux qu'ils ont obtenus de leur nouvelle approche analytique, et ils ont mis en évidence les rapports entre résistance et frottement dont ils se sont servis à l'étape suivante. Dans la seconde étape, ils ont opéré une extrapolation visant à reproduire à partir des caractéristiques connues, celles d'un navire en vraie grandeur ayant un déplacement de 30 000 tonnes. Mettant en oeuvre une glace modèle d'une épaisseur et d'une résistance déterminées, et utilisant un facteur de similitude approprié, ils ont obtenu les caractéristiques correspondant à celles d'un navire de 30 000 tonnes se déplaçant dans des glaces de 1 m d'épaisseur et de 500 kPa de résistance.

La phase de « paramétrisation » du bau a mis en évidence des écarts de résistance qui ont pu être expliqués en termes semi-quantitatifs.

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Summary

This report describes the third phase of work related to the analysis of length and beam effects on icebreaking performance. The report draws extensively on two previous phases of the program carried out by Melville for the Transportation Development Centre (TDC).

The objective of this work was to evaluate the parametric influence of length, breadth, L/B ratio and bow form on the resistance of a hull form in ice. The analysis was accomplished with a standard analysis procedure that was used to systematically evaluate the performance of the model hulls. These had previously suffered in two respects: the type and analysis normally depended on the particular engineer who undertook the test; and the available analysis tools at IMD were not conducive to analysis and general use without access to the computer and an extensive understanding of the VAX system.

The analysis was conducted in two parts. The first part reviewed the test results at model scale and compared the new analysis approach to previous work. Relationships between resistance and friction were also established for use later in the report. The second part of the analysis scaled each model to a displacement of 30000 t. This was accomplished by using target ice thickness and strength that, in association with the appropriate scale ratio, resulted in a ship of 30000 t in 1 m thick, 500 kPa ice.

A computer program, DATAN, was used to analyze the data. The program uses all the relevant data from the tests and includes automatic or manual selection of the time series data samples and non dimensional or dimensional analysis of the raw data to target ice thicknesses and strengths. The analysis procedure also includes corrections for friction. The program permits the user to display any of the data from any ship either in isolation or in conjunction with other ships. The output permits a range of variables to be plotted, including resistance vs displacement, length, L/B, beam, Kashteljan coefficient, Shimanski coefficient and speed vs thickness.

A total of 23 hulls were analyzed and presented in the form of resistance vs Kashteljan and Shimanski coefficient. The analysis has shown that the performance of a hull can be related to the Kashteljan and Shimanski coefficients, but with only limited confidence and only in a comparative sense between two similar types of hull form. The differences between the resistances found in varying the breadth of a candidate bow as revealed in the beam variation phase of this project were explained in semi quantitative terms.

The report recommends: improvement of the definition of icebreaker hull forms to include the influence of the shape of the bow along the waterline; integration of additional models, already tested at IMD, into the DATAN analysis; integration of the DATAN program into the Ice Carriage data acquisition system so that model test results can be immediately analyzed and reviewed to identify problems while the ice is available for additional testing.

SOMMAIRE

Ce rapport décrit les travaux de la phase III de la recherche portant sur l'influence du bau et de la longueur de la section médiane d'une coque sur les performances d'un brise-glace, et renvoie aux travaux des deux phases précédentes conduits par le contractant (Melville Shipping Ltd) pour le compte du Centre de développement des transports (CDT).

La phase III avait pour objectif d'analyser «paramétriquement» l'influence de la longueur (L), du bau (B), du rapport L/B et de la forme géométrique de la proue sur la tenue à l'action des glaces d'une coque de forme donnée, analyse menée selon la procédure standard ayant servi à l'évaluation systématique de maquettes comportant une coque segmentée. Deux constatations ont permis d'éclairer les insuffisances dont avaient souffert les analyses antérieures : la procédure et l'analyse elle-même sont conditionnées par le chercheur qui les prend en charge, et les outils d'analyse dont disposait l'Institut de dynamique marine (IMD) ne pouvaient servir aux fins d'analyse sans que le programme informatique existant ne soit modifié et sans une connaissance approfondie du VAX.

L'analyse a été menée en deux étapes. Dans la première, les chercheurs ont procédé à l'examen des résultats antérieurs et à leur comparaison avec ceux qu'ils ont obtenus de leur nouvelle approche analytique, et ils ont mis en évidence les rapports entre résistance et frottement dont ils se sont servis à l'étape suivante. Dans la seconde étape, ils ont opéré une extrapolation visant à reproduire à partir des caractéristiques des maquettes celles d'un navire en vraie grandeur ayant un déplacement de 30 000 tonnes. Mettant en oeuvre une glace modèle ayant une épaisseur et une résistance déterminées et utilisant un facteur de similitude approprié, ils ont obtenu les caractéristiques correspondant à celles d'un navire de 30 000 tonnes se déplaçant dans des glaces de 1 m d'épaisseur et de 500 kPa de résistance.

Les données obtenues ont été analysées par DATAN, un programme informatique qui utilise toutes les données utiles provenant des essais, qui permet la sélection automatique ou manuelle de séries chronologiques de données, ainsi que l'ajustement des données brutes sous forme tant dimensionnelle qu'adimensionnelle jusqu'à les faire correspondre à des valeurs normalisées d'épaisseur et de résistance des glaces. Cette procédure permet également de prendre en compte l'effet du frottement. Elle permet aussi d'obtenir une série de graphiques en faisant varier une vaste gamme de paramètres les uns en fonction des autres, notamment le paramètre de résistance en fonction : du déplacement, de la longueur, du bau, du rapport L/B et des coefficients de Kashteljan et de Shimanski, ainsi que la vitesse en fonction de l'épaisseur.

Au total, 23 formes de coque ont été analysées, et les résultats ont été présentés sous forme de graphiques montrant la résistance en fonction des coefficients de Kashteljan et de Shimanski. L'analyse a montré que les performances d'une forme peuvent être reliées aux coefficients mentionnés mais en ne dégageant qu'une limite de confiance limitée et en restant dans le domaine de la comparaison entre deux formes géométriques similaires. La phase de paramétrisation du bau a mis en évidence des écarts de résistance qui ont pu être expliqués en termes semi-quantitatifs. Cette constatation confirme la conclusion tirée précédemment, à savoir que la résistance à la marche, tout en étant influencée par la forme géométrique de la proue, l'est relativement peu par le rapport Longueur/Bau.

Le rapport formule les recommandations suivantes : affiner la définition de la forme géométrique d'une coque de brise-glace par la prise en compte de la forme de la proue à la ligne de flottaison; intégrer dans le programme DATAN les données concernant les nouvelles maquettes essayées à l'IDM; permettre au programme DATAN d'analyser les données au fur et à mesure qu'elles sont produites par les essais sur maquettes afin d'identifier les difficultés qui pourraient surgir et ce, pendant que la glace modèle est encore disponible pour d'autres essais.

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1.0 Introduction

This report describes the third phase of work related to the analysis of length and beam effects on icebreaking performance. The report draws extensively on two previous reports prepared by Melville for the Transportation Development Centre (TDC) (Reference 2 and 3).

These two reports (Melville 1988, 1990) describe the work on two sets of model tests with the MV Arctic, a 30,000 DWT ice classed OBO carrier. The first set of tests used the existing hull form (fitted with a Melville bow) and the original hull form (fitted with a "White" type bow) with different lengths of parallel midbody. This permitted the analysis of multiple L/B ratios for the same bow and stern form. The second set of tests used the existing hull form together with two other models parametrically identical to the existing hull with the exception that the hull beam was increased by 20% for one hull and decreased 20% for the second. This permitted the analysis of L/B ratios at different values of length and beam. These were further analyzed by plotting the data from each different model at different scales so that the resultant full scale ships had identical waterplane areas.

The objective of the work described in this report is to extend this analysis to other ships tested at the Institute for Marine Dynamics in St. John's Newfoundland.

The work is described in three parts. The first part, Section 2 of this report, develops the standard analysis procedure used to analyze the test data. The second part, Section 3, describes the use of the program with an individual test program and the third part, Section 4 of this report describes the comparative analysis between the test programs and the resultant length, breadth and displacement relationships.

The analysis and associated computer program is specifically designed for resistance tests in ice. However, there is no reason that with some modifications it cannot be used for self propulsion in ice or open water analysis.

There have been a broad range of models tested at IMD over the last few years. All those that could be obtained and which still existed in the IMD computer system were accessed for the analysis. From those a series of different hulls were analyzed. Some are based on the same ship but incorporate different bow forms. The ships analyzed are shown in Table 1 and the tests are defined in detail in Appendix 2.

It can be seen from the table that the hulls have a range of L/B ratios of 4.18 to 11.29 and a range of different bow forms from a spoon and Beaufort type bow to conventional CCG bow designs of the 1960s.

Table 1
Hull Forms Included in the Analysis

SHIP	BOW FORM	LENGTH [m]	BEAM [m]	DRAUGHT [m]	BLOCK COEFF	DISPLACEMENT tonnes	L/B	MODEL SCALE	COMMENTS
ARCTIC	WHITE	196.61 248.46 124.14	22.86 22.86 22.86	10.96 10.96 10.96	.757 .814 .613	38,226 51,512 19,573	8.60 10.87 5.43	30 30 30	3 FRICTION COEFFICIENTS
ARCTIC	MELVILLE	206.16 258.00 171.87 133.71	22.86 22.86 22.86 22.86	10.96 10.96 10.96 10.96	.728 .781	38,672 51,899	9.02 11.29	30 30	3 FRICTION COEFFICIENTS
ARCTIC	MELVILLE	206.16 160.39	27.43 27.43	10.96 10.96	.728 .654	46,408 32,398	7.52 5.85	30 30	
ARCTIC	MELVILLE	137.49 164.88 206.16	18.29 18.29 18.29	10.96 10.96 10.96	.601 .666 .731	17,018 22,611 31,034	7.52 9.01 11.27	30 30 30	
SA-15	ORIGINAL MELVILLE	160.47 164.18	24.12 24.12	9 9	.708 .697	25,320 25,467	6.65 6.81	28 28	
CCG BERNIER	ORIGINAL R-CLASS BEAUFORT	64.62 64.62 64.62	14.69 14.69 14.69	4.87 4.87 4.87	.646 .623 .649	3,116 3,006 3,208	4.4 4.4 4.4	15 15 15	
CCG NORMAN MCLEOD ROGERS	ORIGINAL R-CLASS	81.15 81.15	19.05 19.05	6.10 6.10	.675 .641	6,522 6,200	4.26 4.26	20 20	
CCG LOUIS S. ST. LAURENT	ORIGINAL R-CLASS MELVILLE	101.8 106.68 106.68	24.36 24.29 24.29	9 8.53 8.53	.585 .561 .545	13,400 12,713 12,365	4.18 4.39 4.39	15 15 15	
R-CLASS	R-CLASS	87.0	19.37	7.2	.6510	8,171	4.49	20	

2.0 Standard Model Test Analysis

2.1 General

The large number of model tests and resultant range of analysis procedures required that a standard methodology was developed for analyzing the resistance data. This standard methodology was developed by Melville in close consultation with IMD. The procedure is focused on resistance tests and includes the analysis of ice, time series tests data and final normalisation.

The computer program and manual specifically developed for this analysis is included as Appendix 1 and describes the use of the computer program. The following text focuses on the technical content of the analysis.

2.2 Ice Data

The ice data is collected as time series data from the ice sheet as it is tempered from the freezing and growing flexural strength of about 100 kPa to the test strength which may be about 20 to 30 kPa. Ice flexural strength is measured in a central location in the tank for monitoring ice tempering and, for some tests, in the designated test area of the model test. The Automatic analysis procedure reads the ice strength data from IMD files which do not identify specific strength values along the ice sheet. As a result this analysis takes the average strength along the ice sheet at the time of the test. In some cases the ice strength was known for each individual test and in these cases the ice strength was input manually.

Ice thickness is usually measured after each model test every two metres along each side of the broken channel. There is, typically, one set of thickness data for the level ice test and one for the presawn test. The thickness used in the analysis is the average thickness calculated from the measured values within the actual test sample.

The crushing and shearing strength, Modulus and density are recorded on the data sheets but not used in the analysis.

The calculation of flexural, shearing and crushing strength can be done with the computer program based on the size of the ice sample. The calculation procedure is described in the computer program manual, Appendix 1.

2.3 Model Test Data Analysis

The analysis of the model test data time history is automatically completed by the computer program based on the speed channel.

The automatic calculation involves moving through the speed channel data and finding those parts of the time history that have a constant speed. These are then selected based on a number of criteria:

- Based on the speed channel, the program runs through the time series data and selects the start and end of each constant speed. A "Constant Speed" is defined as one that remains constant to within 0.005 m/sec for 5 seconds.

- The start point of the data sample or "Set", which will be used in the analysis, is calculated to be the start of the constant speed, plus the time taken for the model to travel its own length at that speed.

- The end point of the data Set is calculated to be the point at which the speed is no longer constant.

- The duration of a Set, defined as the time between the start and end points, is then compared with the time taken for the model to move its own length.

- The time taken for the model to move its own length is a function of the model length (L) and speed (v)

$$Time = \frac{L}{v}$$

- If the length of the Set is greater than the time necessary for the model to move half its own length or ten seconds, then it is considered to be acceptable.

- If the length of the Set is less than the time necessary for the model to move half its length but more than a quarter of its length or is less than ten seconds, then the Set is considered to be acceptable, but is flagged for future reference.

- If the length of the Set is less than the time necessary for the model to move a quarter of its length, then the Set is rejected.

- If the Set is longer than 5 seconds and has an average speed lower than 0.005 m/sec, the Set is assigned to be "Zeros" that may be used for calibration.

Based on these definitions of the Set, statistical values are calculated for the Mean of the samples in each Set, the Maximum value in each Set, the Minimum value in each Set and the Standard Deviation in each Set.

If, for any reason, the user requires to modify a set selected by the computer, then this can be done and a "Comment" is assigned to that data point. This is important since it clearly identifies any "user interpretation" or "user manipulation" that was associated with any data point

and that can influence the results. The program also permits the user to enter notes on each set to describe why changes were made.

2.4 Data Analysis

Each test will be represented by ice properties from the ice data screen and the selected data points representing the mean samples taken from the time series. The analysis section of the program allows the user to normalise the ice resistance data to target values of ice thickness and strength using a number of different methods. The analysis methods may be divided into two types, the Non-Dimensional method and the Dimensional method. The detailed description of each method is included in the computer program manual, Appendix 1 or may be obtained from the original source listed in the bibliography.

2.5 Analysis Verification

To establish the validity of the standard test procedure, a sample set of tests were analyzed and compared with previously analyzed data. Two ice sheets were selected that were tested with the MV Arctic as part of the BEAM variation program (Melville 1990). The two ice sheets were 30 and 40 mm thick and tested with Arctic fitted with the Melville bow. The tests were notated as BEAM1 and BEAM5.

The first check was to determine if the automatic selection of the samples from the time series was consistent. This is shown in Table 2.

Table 2 illustrates the comparison between the two analysis procedures for BEAM 1 and BEAM 5. The values representing the DATAN analysis were generated fully automatically with no manual corrections.

It can be seen from the table that the DATAN analysis also selected a "Zero Speed" data point for the BEAM 1 level ice and presawn resistance and for the BEAM 5 level ice resistance. These were not calibration zeros and may be ignored for the purposes of this comparison. Speed values were identical for all the samples.

The DATAN and original values for the BEAM 1 level ice resistance and presawn resistance are fairly close although other test programs have given closer correlation. However, 12% is not unreasonable. The BEAM 5 level ice resistance is not a close comparison and illustrates one of the significant advantages of the DATAN analysis technique. A review of the time series of this data set revealed that there had been a problem during the test and that there had been an unusual disturbance towards the end of the second and third speed interval. There was no comment or recognition of this problem in the original report and the extent to which it influenced the final data and the exact cause of the disturbance is unknown.

Using the manual selection capability in the DATAN program it was possible to correct the automatic cursor positions. This was done for the second and third test. It may be noted that when this is done the DATAN program automatically assigns a comment to these data sets

Table 2
Comparison Between DATAN Analysis and Original Analysis on BEAM Variation Program

	DATAN Analysis			Original Analysis			% Difference	
	Speed [m/sec]	Level Resistance [N]	Presawn Resistance [N]	Speed [m/sec]	Level Ice Resistance [N]	Presawn Resistance [N]	Level Ice	Presawn Ice
BEAM1	-.022	5.0	2.4	-	-	-	-	-
	.166	66.6	16.9	.166	59	19	12.8	-11.1
	.307	72.9	22	.307	73	22	-	-
	.448	73.2	32.5	.448	71.56	32	2.3	1.6
	.578	88.9	39.5	.578	94	38	-5.4	4.0
BEAM5	.022	18.6	-	-	-	-	-	-
	.190	73.7	29.9	.190	68	35	8.4	-14.6
	.331	121.2	41.8	.331	93	41	30.3	2
	.471	122.9	49.1	.472	101	49	21.7	-
	.601	112.2	59.2	.601	122.8	59	8.6	-
BEAM 5 Data After Manual Correction								
BEAM5	.331	91.9	41.8	.331	93	35	-1.2	2
	.471	106.5	49.1	.472	101	41	5.5	-

indicating that they have been manually changed. In addition, DATAN allows a "Note" to be written and assigned to each sample for future reference.

The new, manually selected, values for the second and third BEAM 5 level ice tests were 91.9 N and 106.5 N which correspond to the original values of 93 and 101 respectively. This represents a -1.2% and 5.5% difference. These are shown on the bottom of Table 2.

The next stage in the analysis verification was to demonstrate the correction procedures. The Dimensional corrections, which are simply linear extrapolations between data points, do not require specific calibration since each calculation can be checked using a simple calculator or by hand.

There are two non-dimensional analysis procedures in DATAN. They were both developed by Dr. Colbourne and with the exception of an added friction coefficient term, are very similar. As a result, although both procedures were validated in the program, only the validation for the first non-dimensional analysis is illustrated here using a spreadsheet program

Table 3
Comparison Between DATAN Non-Dimensional Analysis and a Spreadsheet Calculation

Target Values		DATAN Correction		Spreadsheet Correction		Difference %
h [mm]	σ [kPa]	Speed [m/sec]	Resistance [N]	Speed [m/sec]	Resistance [N]	
30	17	.166	50.49	.166	50.35	-
		.307	61.53	.307	62.06	-1
		.448	70.77	.448	71.85	-1.5
		.578	78.61	.578	80.18	-2
40	17	.189	75.18	.19	75.19	-
		.331	91.02	.331	91.8	-
		.471	104.35	.472	105.74	-1.3
		.601	115.58	.601	117.38	-1.5
Breaking Coefficient		5.49		5.42		1
Breaking Index		-1.41		-1.41		-
Clearing Coefficient		84.31		83.43		1
Clearing Index		-1.87		-1.84		2

to validate the least squares regression. The spreadsheet program and analysis procedure was identical to the original analysis of the data. The values determined by the DATAN program were input to the spreadsheet and the resultant coefficients and corrected resistances are shown in Table 3.

It can be seen from the table that the DATAN program regression analysis is working correctly and produces values within 2% of the spreadsheet calculation. This is reasonable since there will be some small differences between the two methods with respect to rounding errors and least squares analysis technique.

3.0 Data Analysis

Each of the sets of model tests were analyzed using the DATAN program and compared with the original report if this was available. The following section describes the analysis conducted on the Arctic results which represent the data analysis conducted on the remainder of the data.

There have been three major test programs with the MV Arctic at the IMD. These are:

Friction Test Program	A series of tests to determine the influence of friction coefficient on the bow and midbody of the hull (Melville 1987).
Length Variation Program	A series of tests to determine the influence of length (Melville 1988).
Beam Variation Series	A series of tests to determine the influence of Beam (Melville 1990).

The matrix of tests which included both the new "Melville" and original bow forms are presented in Appendix 2, Tables 1 to 5. The results from the analysis are substantially the same as the original data. Each set is discussed in the following notes.

a) Friction Test Program

A total of 13 ice sheets were tested with three friction coefficients on the bow and/or midbody of the MV Arctic. However, two of the initial friction coefficients, the medium and rough, were found to have very similar friction coefficients. As a result, a fourth rougher surface was prepared and tested. The original medium and rough surfaces were grouped as medium.

Tables 1 and 2 in Appendix 2 illustrate which surfaces were rough and which smooth.

The DATAN analysis of the Friction test program yielded similar results to the original data.

Two analysis methods were used to normalise the data to target values, a dimensional correction based on the presawn tests and a second level ice thickness and Colbourne's non-dimensional analysis. The non-dimensional analysis uses a group of level ice and presawn ice sheets to develop a corrected or normalised data line. The disadvantage of this approach is that it may influence the data and obscure a trend. This may be the case for ice thickness which is assumed to be linear in the non-dimensional analysis but which is generally thought to be between unity and two.

Excepting the generic correction methods for thickness and strength, the dimensional analysis requires a presawn test to correct for strength and a second ice sheet to correct for thickness. Unfortunately, all the tests were not run in two ice thicknesses; however, since ice thicknesses are usually obtained fairly accurately, using the generic method or simply not correcting for thickness may not significantly influence the data.

Figure 1
Comparison between Dimensional and Non-Dimensional Analysis
for the MV ARCTIC Friction Ice Test Program
Thickness = 50 mm, Strength = 17 kPa, Friction = 0.06

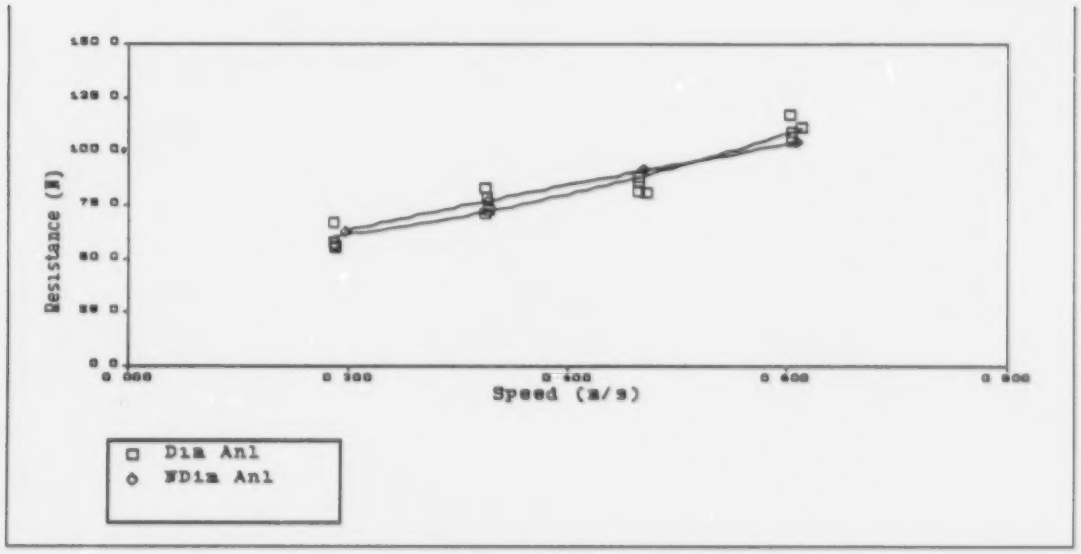


Figure 1 illustrates the comparison between the non-dimensional and dimensional analysis procedures for the base case model in 50 mm. The dimensional analysis has been corrected for ice strength and thickness and a fair line drawn through the data. Clearly, there is little difference and a similar relationship exists for the 40 mm ice sheet.

Figure 2 illustrates the same relationship between the non-dimensional analysis and the dimensional analysis with the strength correction only. Clearly, the influence of the thickness deviations are small.

The three friction coefficients were tested on the bow and midbody of each model. Testing each configuration permitted an analysis of the influence of the friction coefficient on the bow and midbody of the model.

Figure 3 illustrates the results from tests with high, medium and low friction coefficients on the model. It should be noted that during the Friction test program the high friction coefficient was only tested on the bow and not on the bow and midbody. As a result, although

Figure 2
Comparison between Dimensional Analysis with Strength Corrected to 17 kPa and Non Dimensional Analysis.
Ice thickness = 50 mm; Friction Coefficient = 0.06

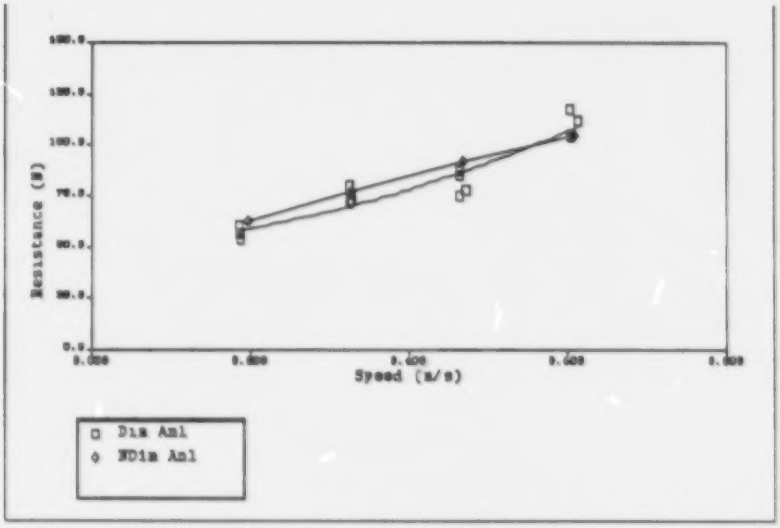
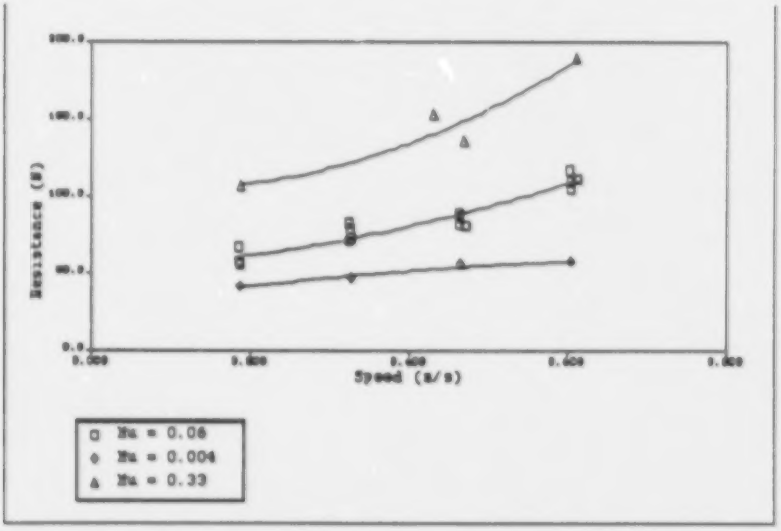


Figure 3
Comparison of Three Friction Coefficients on the ARCTIC Base Hull Form
Thickness = 50 mm, Strength = 17 kPa, Friction = 0.004, 0.06 and 0.33



the medium and low friction hulls were fully coated with their respective coatings, the high friction hull had a medium friction midbody. The results of the comparison indicate that the influence of the friction coefficient is significant.

Additional tests were conducted with medium and low bow frictions combined with medium and low midbody friction surfaces.

Figure 4
Influence of Midbody Friction on the ARCTIC
Thickness = 50 mm, Strength = 17 kPa
Friction Coefficients = 0.004 and 0.06

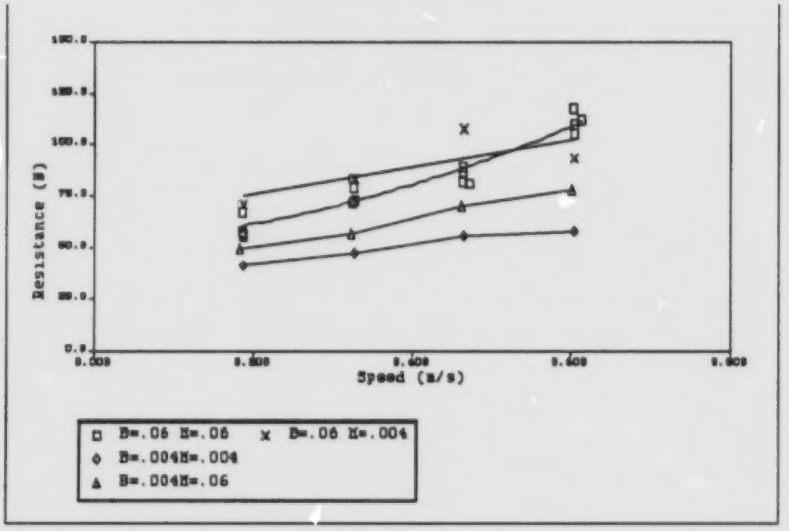


Figure 4 illustrates the relationship between the influence of the bow and the midbody. It is evident that the midbody friction is less significant than the bow.

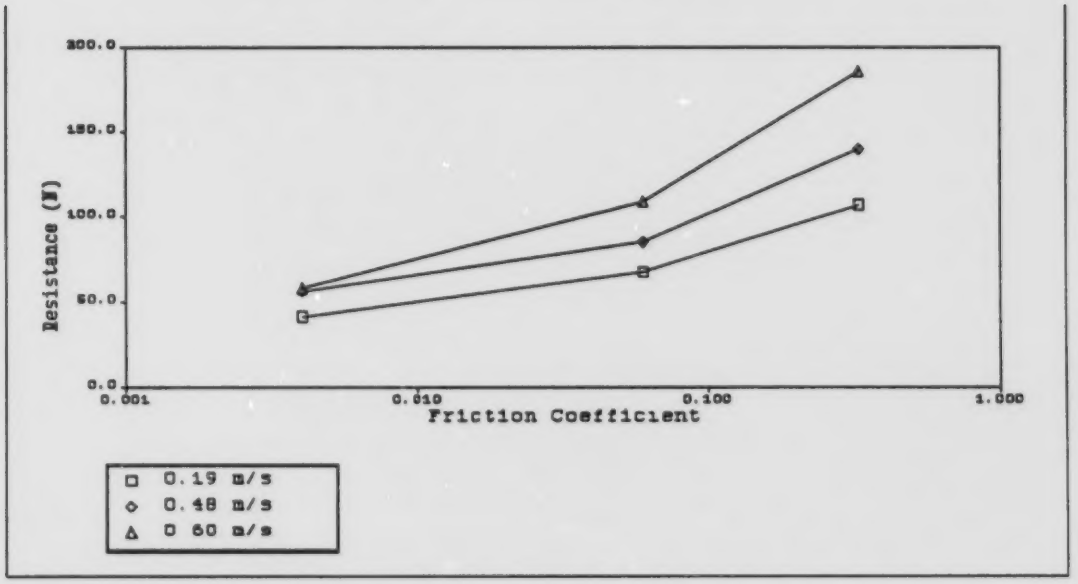
Figure 5 illustrates the relationship between the resistance and the Log of friction coefficient for the series of hulls in Figure 3. The significant influence of friction is evident from the curves and this result duplicates the original analysis of this data.

It should be noted that the high friction curve on Figure 5 is for the model tested in the Friction test program with a high friction bow and medium friction midbody.

b) Length Variation Program

The objective of the Length Variation Program was to investigate the influence of length on the MV Arctic. This was accomplished with a set of tests to investigate the friction coefficient variations observed in previous tests and then a series of tests with the MV Arctic varying midbody length.

Figure 5
Resistance vs Log Friction from the Friction Program
Ice thickness = 50 mm; Ice strength = 17 kPa



A total of 14 ice sheets were tested with different bows, different midbody lengths and different friction coefficients on the MV Arctic. Friction coefficients were recorded before all tests and all the standard tests, flexural strength, modulus and thickness, were conducted on the ice. The tests included the existing Arctic, that was shortened and extended by adjusting the parallel midbody, and the original Arctic, also shortened and extended by adjusting the parallel midbody. Three friction coefficients were also tested: these corresponded to the Friction test program and were tested on the original and existing Arctic.

Two ice sheets, 50 and 40 mm, were repeated from the friction test program with the base ship. Figure 6 illustrates the correlation between the two tests at 50 mm. Clearly, the midbody test yielded high resistance values than the friction test program. During the original analysis, this was partly attributed to problems with the ice sheet and the data was manipulated and subsequently averaged between the two sets. However, the objective of the current analysis was to maintain a consistent analysis procedure and, as a result, this methodology was not applied.

An additional feature in the DATAN program is the ability to correct the friction coefficient from nominal values based on the friction test analysis.

Figure 7 illustrates the same correlation shown in Figure 6 with the exception that the midbody tests were assumed to occur at a friction of 0.1 and subsequently corrected to 0.06. Clearly, this gives a very good correlation. A second test was also performed in both the midbody and friction test program.

Figure 6
Comparison Between Midbody and Friction Test Results
Thickness = 50 mm, Strength = 17 kPa

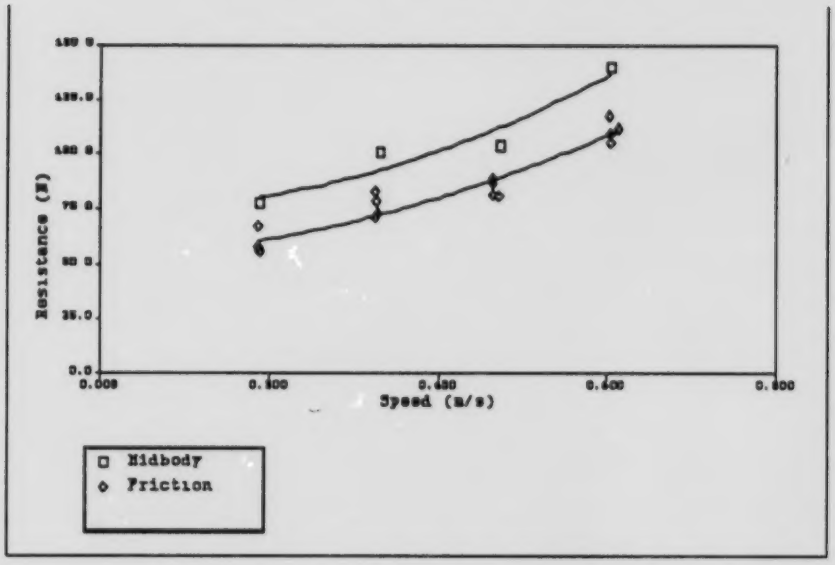


Figure 7
Comparison Between the Friction and Midbody Tests
Thickness = 50 mm, Strength = 17 kPa, Friction = 0.06

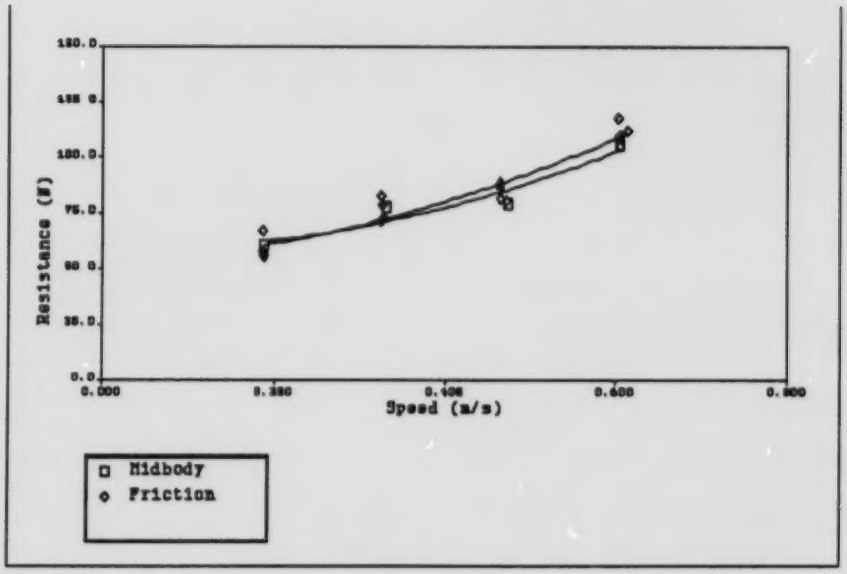
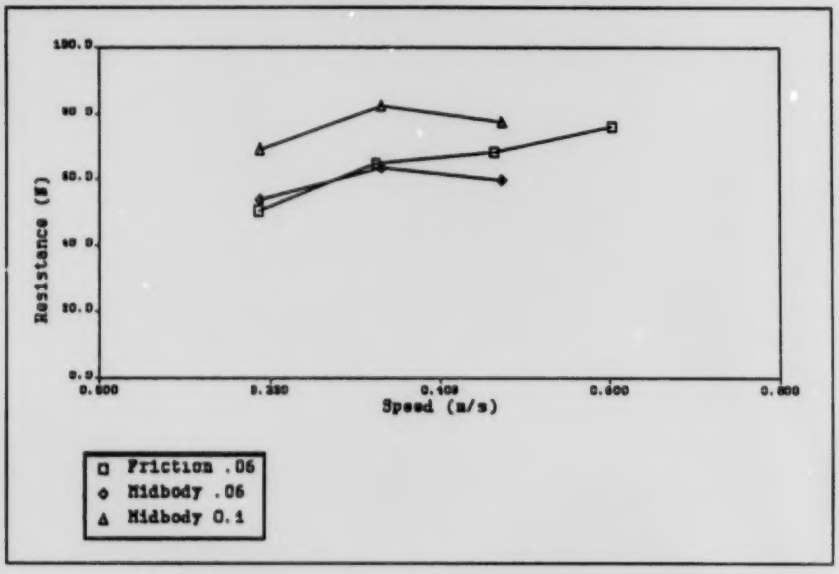


Figure 8 illustrates the comparison between the Friction and midbody test program at 40 mm. The figure shows the midbody data at 0.1 and 0.06. Clearly, although the correlation is not so good, the friction correction has resulted in a more consistent data set and would indicate that the midbody models were tested at a friction of 0.1.

Figure 8
Comparison Between the Friction and Midbody Tests
Thickness = 40 mm, Strength = 17 kPa



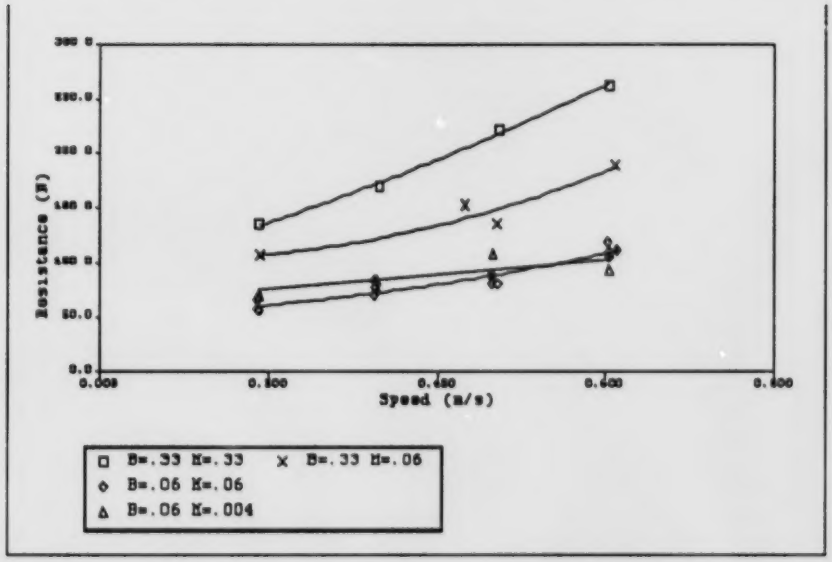
It may be noted that apart from casual hull cleaning, the hulls tested as part of the midbody tests were not repainted and the higher friction could be accounted for by general handling and perhaps aging of the hull paint during the year that passed between the tests.

A further test of significance during the midbody test program was a high friction bow and midbody test that complemented the tests during the friction test program.

The original set of tests described above included bow and midbody combination of frictions at 0.06 and 0.004. The high, 0.33, friction coefficient was only tested on the bow of the model with the 0.06 friction on the midbody. The results of these tests indicated that the influence of midbody friction was not significant.

To determine the influence of midbody friction at high values of friction, a model of the Arctic was tested with high friction bow and midbody. This test was designed to complement the friction tests described above. The results of the high friction test in the midbody test program showed a significant influence of midbody friction on resistance. Figure 9 presents the data from the high friction coefficient test in addition to the data collected from the friction test

Figure 9
Midbody and Bow Friction Resistance on the ARCTIC
Thickness = 50 mm, Strength = 17 kPa, Friction 0.06 and 0.33



program for the high friction, 0.33, surface on the bow with 0.06 on the midbody. The results from the medium, 0.06. and smooth, 0.004, tests are also shown on the figure for comparison.

Figure 10 presents the resistance vs Log friction coefficient relationship based on the tests of the existing Arctic. It may be noted that a further relationship was developed for the short Arctic (Ref. 1). The resultant relationship is used as the basis for the friction correction adopted for the dimensional analysis in DATAN.

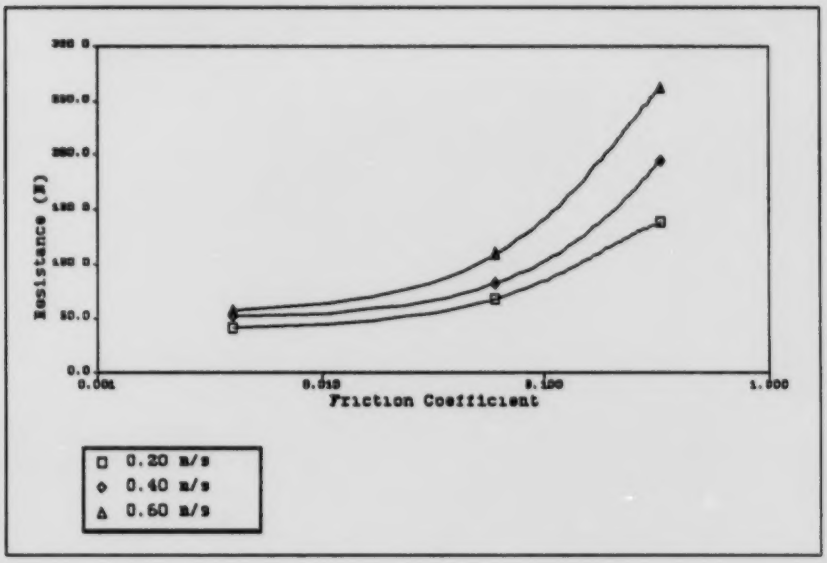
The friction correction takes the form of:

$$R_{cor} = R_{meas} \cdot \left(\frac{R_2}{R_1} \right)$$

where

R_2 = Resistance of standard hull at target friction.
R_1 = Resistance of standard hull at tested friction.
R_{cor} = Corrected resistance of the subject hull.
R_{meas} = Measured resistance of the subject hull.

Figure 10
Resistance vs Log Friction Coefficient
Ice thickness = 50 mm, Ice strength = 17 kPa



The resistance of the standard hull is obtained from a relationship derived from model tests conducted at different friction coefficients. The analysis used the tests conducted on the Arctic as representing the only analysis of friction coefficient on a specific hull form.

The relationship has been assumed to be an exponential function of resistance and friction coefficient with two constants.

$$R = a \cdot e^{b\mu}$$

R = Resistance
a = Constant Coefficient
b = Constant Index
μ = Friction Coefficient

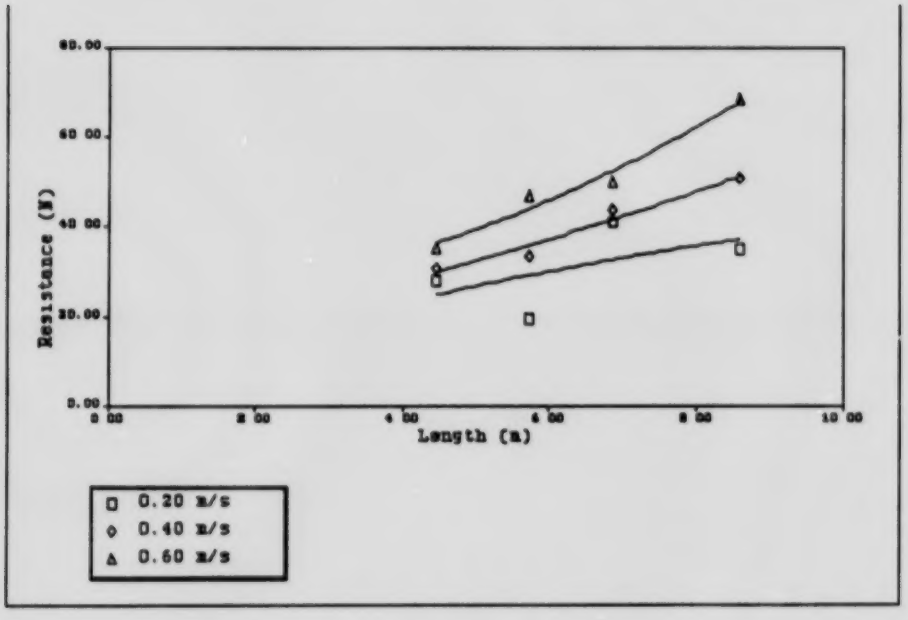
The values of "a" and "b" are a function of speed and may be calculated for any series of model friction model tests. However, due to the form of the exponential curve through the Arctic data, the friction correlation was very poor if the three friction coefficients (0.33, 0.06 and 0.004) were all used to develop the correction curves. As a result experience with using the friction correction has demonstrated that the data should be represented by two exponential curves. The first based on the low, 0.004, and medium, 0.06, tests and the second on the medium, 0.06, and high, 0.33, tests. Values of the resultant correction constants are presented in Table 4.

Table 4
Friction Coefficient Correction Factors used in the DATAN Analysis

	Using Data from 0.33, 0.06 and 0.004		Using Data from 0.33 and 0.06		Using Data from 0.06 and 0.004	
Model Speed	a	b	a	b	a	b
.1885	157.04	0.273	232.32	0.496	88.41	0.153
.3286	212.57	0.297	278.15	0.450	143.27	0.214
.4560	270.83	0.314	397.98	0.533	153.97	0.196
.6048	340.79	0.347	475.86	0.536	208.81	0.244

The objective of the length variation tests was to investigate the influence of length on the resistance of the Arctic. Figure 11 illustrates the relationship for the models of the existing Arctic as tested. Although there is scatter in the data, there is a general upward trend that duplicates the results from the original analysis.

Figure 11
Resistance vs Length from the Midbody Tests
Ice thickness = 30 mm; Ice strength = 17 kPa

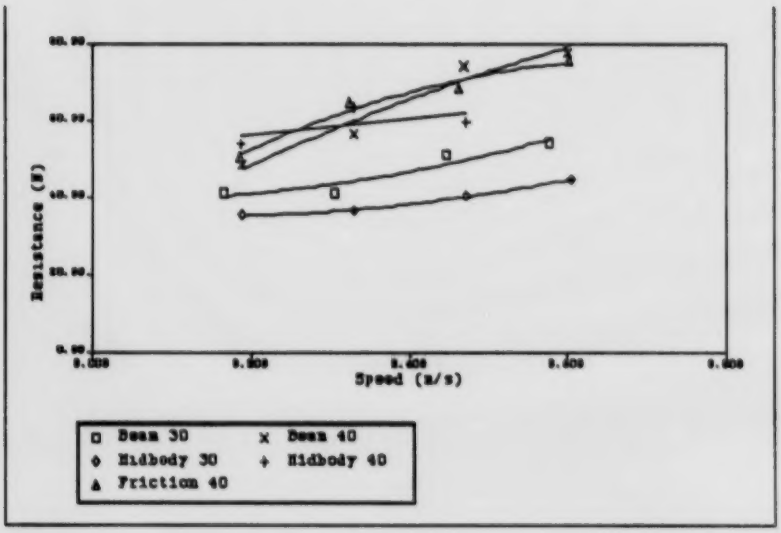


c) Beam Variation Program

A total of 8 ice sheets were tested with different beams and different midbody lengths on the MV Arctic. The tests were run with the existing Arctic with the beam increased and decreased by 20%. The models were also shortened and extended by adjusting the parallel midbody.

Two ice sheets were tested as part of the Beam series of tests to correlate with previous work. These were the base beam base length and the Base beam long length models. Like the comparison between the midbody and friction tests, the comparison with the beam tests resulted in a higher friction coefficient than the midbody tests. The friction coefficient that produced a correlation between the midbody and beam tests was 0.12, for the 40 mm tests. For correlation between the beam and midbody tests at 30 mm would have implied that even higher friction coefficients were present during the Beam tests and this is not thought to be the case. As a result, subsequent Base Beam, Base Midbody, Melville Bow model data in 30 mm ice is represented with the midbody test data which correlated well with the initial Friction tests series.

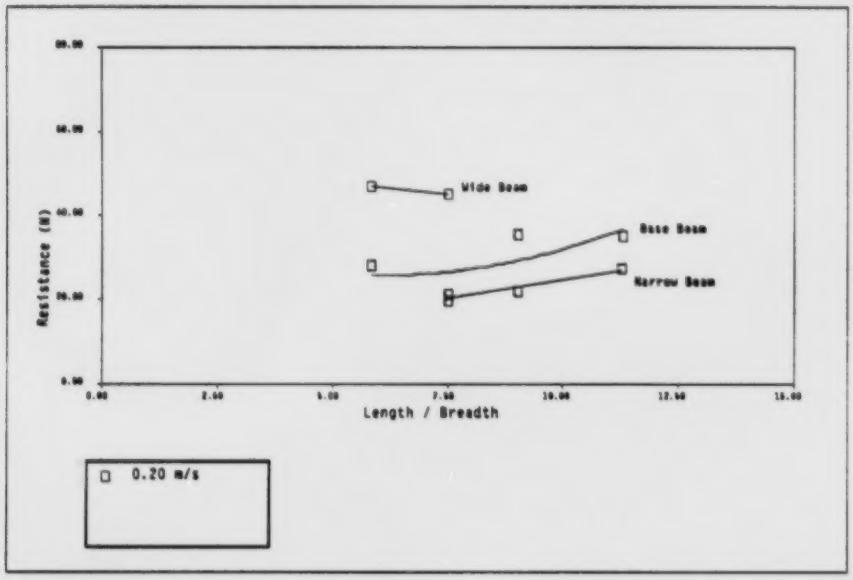
Figure 12
Comparison Between the Midbody and Beam Tests Corrected from assumed test value of 0.2 to Target Value of 0.06
Ice thickness = 30 mm; Target friction = .06



The correlation for the Friction, Midbody and Beam tests at 30 and 40 mm is shown in Figure 12. The assumption that the friction coefficient increased, from initially 0.06 during the Friction tests conducted in 1986, to 0.1 during the midbody tests conducted in 1989, to 0.12 during the Beam tests conducted in 1989, is only supported by comparing the model test results. It is considered that this is not entirely unreasonable due to the general handling of the model in the intervening years and perhaps a natural aging of the hull paint finish. However, this and

other test result anomalies clearly demonstrate a need to more accurately define the friction coefficient during model tests with a more consistent and accurate method.

Figure 13
Length/ Breadth from the Friction, Midbody and Beam Variation Test Programs
Friction Coefficient = 0.06, v = 0.2 m/sec



The primary objective of the beam series was to add additional beam and length data to the midbody and friction test programs. Figures 13 and 14 illustrate the data collected from the three test series as resistance vs L/B ratio at 0.2 and 0.6 m/sec respectively. There are three curves for each speed. The upper curve is the data from the wide beam model at two lengths. It can be seen from the figures that at higher speeds the resistance tends to increase with L/B and at lower speeds the resistance drops. These trends are not considered to be significant since there are only two data points and the resistance difference between the base length wide model and the short wide model is small.

The differences between the two wide beam models is illustrated in Figure 15 which presents the resistance vs speed for the wide beam model with the base and short midbody. The results of the tests indicated that the midbody had a small influence on the performance of the wide model and that the difference between the upper and lower speed data points is largely a function of data scatter rather than any real trends in the data.

Figure 14
Length/ Breadth from the Friction, Midbody and Beam Variation Test Programs
Friction Coefficient = 0.06, v = 0.6 m/sec

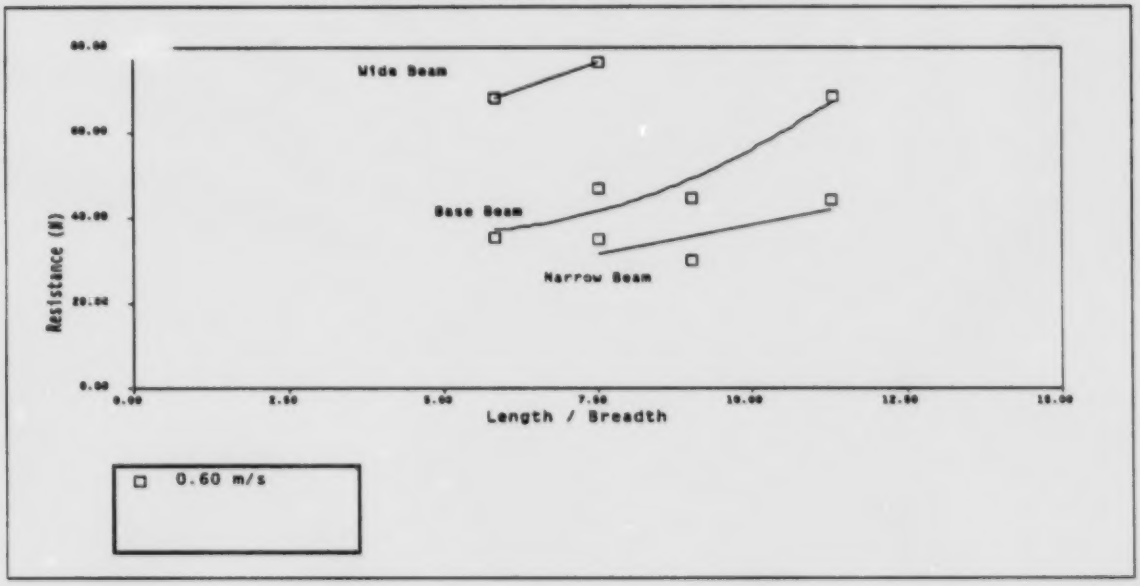
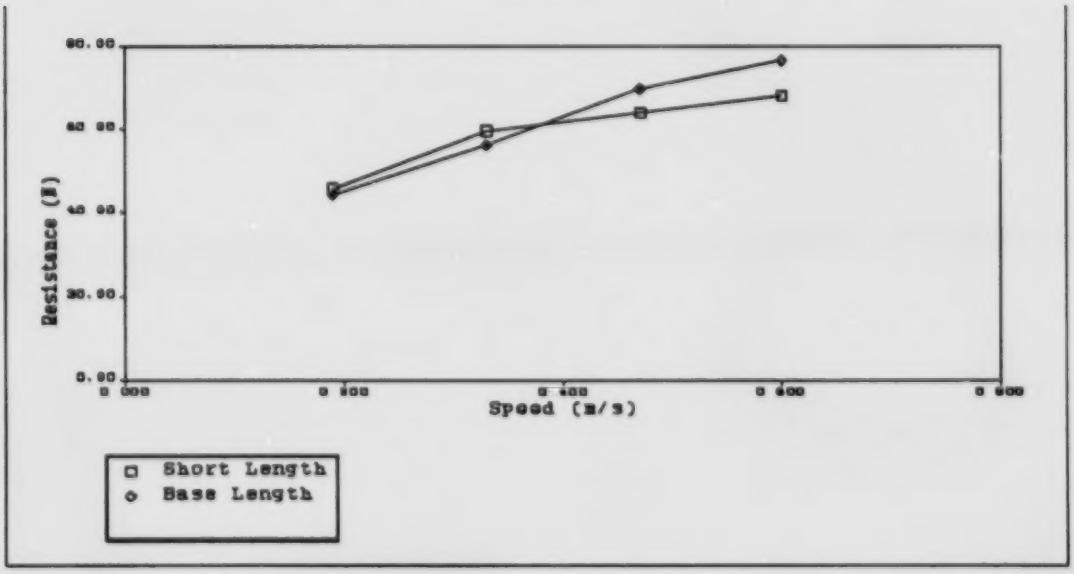


Figure 15
Wide Beam Model with Base and Short Lengths
Ice thickness = 30 mm; Ice strength = 17 kPa



4.0 Hull Form Analysis

A primary objective of this work was to explore the definition of hull form. Currently, the only widely used definitions are the Shimanski and Kashteljan coefficients. These may be defined as the integrated average of the direction cosines along the length of the bow. They are not sensitive either to the location of any particular angle on the bow or to influence of flare angles and waterline angles in combination. The Kashteljan coefficient is usually referred to as the clearing coefficient and the smaller this number, the lower the resistance. The Shimanski coefficient is referred to as the breaking coefficient and the larger this number the lower the resistance.

Table 5 illustrates the Kashteljan and Shimanski coefficients that were calculated from available data for the models included in the analysis.

The beam variation series was conducted on a series of hulls that had only been increased in beam and, as a result, they all have the same Kashteljan coefficient. However, they also have different lengths and beams. Therefore, to normalise the results so that they may be compared, they are presented as resistance normalised to a constant displacement.

The normalisation simply takes each model and scales it to a selected displacement. This may, or may not, be the same scale necessary to reproduce the original hull that the model was designed to represent. The selected displacement for the normalisation is 30,000 tonnes. This was based on the mean of the hulls available in the analysis which ranged from over 50,000 to 3,000 tonnes. Table 6 illustrates the calculation of the necessary ice thickness, ice strength and model scale values to perform the normalisation. The table includes only those test values used in this analysis. The target ice strength is 500 kPa and the target ice thickness is 0.9 m.

It may be noted that the second phase of this project (Melville 1990) presented the Arctic data at constant waterplane area with resistance vs L/B ratio. This resulted in relationships between resistance and length-breadth ratio that were not consistent between the different models tested. Figures 16, 17 and 18 duplicate the results from the phase two project with the exception that the data is plotted as constant displacement. The variations between these plots and the original relationships in the phase two report are largely due to the different scales. For example, the Increased Beam ship was corrected to a constant waterplane of 4,126 m^2 with a scale of 27.38. The same model corrected to a constant displacement of 30,000 tonnes requires a scale of 25.94. This affects both the scale applied to the resistance and the selection of the target ice thicknesses. Other variations are the result of the standard analysis procedure used during the phase three test analysis which replaced the original analysis.

Table 5
Shimanski and Kashteljan Coefficients used in the DATAN Program

	Kashteljan Coefficient	Shimanski Coefficient
ARCTIC: BBBLMB	1.231	3.191
ARCTIC: BBBLOB	1.658	2.420
ARCTIC: NBBLMB	1.230	3.871
ARCTIC: WBBLMB	1.240	2.734
NORDIC: Melville Bow	1.270	2.358
NORDIC: Original Bow	1.593	2.292
BERNIER: Original Bow	2.189	2.569
BERNIER: R-Class Bow	1.503	2.908
BERNIER: Beaufort Bow	1.308	0.927
ROGERS: Original Bow	2.319	2.520
ROGERS: R-Class Bow	1.503	2.911
LOUIS: Original Bow	1.676	2.337
LOUIS: R-Class Bow	1.505	3.187
LOUIS: Melville Bow	1.262	3.840
R-CLASS	1.53	2.210

Table 6
Calculation of Normalised Data from Model Test Data

MODEL	FRICTION COEFFICIENT	DISP	SCALE	LENGTH	BEAM	L/B	REQUIRED SCALE	CORRECTED LENGTH	CORRECTED BEAM	MODEL SCALE VALUES			CORRECTION METHOD	
										CORRECTED DISPLACEMENT	CORRECTED THICKNESS	REQUIRED STRENGTH	THICKNESS	STRENGTH
		m^3		m	m			m	m		mm	mm		
BBBLOB	0.06	38,226	30	196.61	22.86	8.60	27.67	181.35	21.09	30,000	32.5	18.1	dR/Dh = 1.5	Presawn
BBLLOB	0.06	51,512	30	248.46	22.86	10.87	25.05	207.49	19.09	30,000	35.9	20.0	dR/Dh = 1.5	Presawn
BBSLOB	0.06	19,573	30	124.14	22.86	5.43	34.59	143.13	26.36	30,000	26.0	14.5	dR/Dh = 1.5	Presawn
BBBLMB	0.06,0.1,0.2	38,672	30	206.16	22.86	9.02	27.57	189.43	21.00	30,000	32.6	18.1	dR/Dh = 1.5	Presawn
BBSLMB	0.10	19,719	30	133.71	22.86	5.85	34.50	153.78	26.29	30,000	26.1	14.5	dR/Dh = 1.5	Presawn
BBILMB	0.10	29,191	30	171.87	22.86	7.52	30.27	173.78	23.07	30,000	29.7	16.5	dR/Dh = 1.5	Presawn
BBLLMB	0.1,0.17	51,899	30	258.00	22.86	11.29	24.99	214.92	19.04	30,000	36.0	20.0	dR/Dh = 1.5	Presawn
WBBLMB	0.07	46,408	30	206.16	27.43	7.52	25.94	178.26	23.72	30,000	34.7	19.3	dR/Dh = 1.5	Presawn
WBSLMB	0.07	32,398	30	160.39	27.43	5.85	29.24	156.33	26.74	30,000	30.8	17.1	dR/Dh = 1.5	Presawn
NBSLMB	0.12	17,018	30	137.49	18.29	7.52	36.24	166.09	22.09	30,000	24.8	13.8	dR/Dh = 1.5	Presawn
NBILMB	0.12	22,611	30	164.88	18.29	9.01	32.97	181.18	20.10	30,000	27.3	15.2	dR/Dh = 1.5	Presawn
NBBLMB	0.12	31,034	30	206.16	18.29	11.27	29.66	203.84	18.08	30,000	30.3	16.9	dR/DH = 1.5	Presawn
SA 15														
ORIG	0.05	25,320	28	160.47	24.12	6.65	29.63	169.80	25.52	30,000	30.4	16.9	Interpolation	Presawn
MELVILLE	0.05	25,467	28	164.18	24.12	6.81	29.57	173.39	25.47	30,000	30.4	16.9	Interpolation	Presawn
CCG BERNIER														
ORIG	0.02	3,116	15	64.62	14.69	4.40	31.91	137.47	31.25	30,000	28.2	15.7	Interpolation	Presawn
R-CLASS	0.02	3,006	15	64.62	14.69	4.40	32.30	139.13	31.63	30,000	27.9	15.5	Interpolation	Presawn
BEAUFORT	0.02	3,208	15	64.62	14.69	4.40	31.60	136.14	30.95	30,000	28.5	15.8	Interpolation	Presawn
CCG ROGERS														
ORIG	0.06	6,522	20	81.15	19.05	4.26	33.26	134.96	31.68	30,000	27.1	15.0	Interpolation	Presawn
R-CLASS	0.06	6,200	20	81.15	19.05	4.26	33.83	137.26	32.22	30,000	26.6	14.8	Interpolation	Presawn
CCG LOUIS														
ORIG	0.14	13,400	15	101.80	24.36	4.18	19.62	133.17	31.87	30,000	45.9	25.5	Interpolation	Presawn
R-CLASS	0.09	12,713	15	106.68	24.36	4.38	19.97	142.03	32.43	30,000	45.1	25.0	Interpolation	Presawn
MELVILLE	0.11	12,365	15	106.68	24.36	4.38	20.16	143.35	32.73	30,000	644.7	24.8	Interpolation	Presawn
R-CLASS	0.04	8,171	20	87	19	4.49	30.85	134.22	29.88	30,000	29.2	16.2	Interpolation	Presawn

Figure 16
Resistance vs L/B Ratio for the ARCTIC Hull
Form with Displacement Normalised to 30,000 tonnes

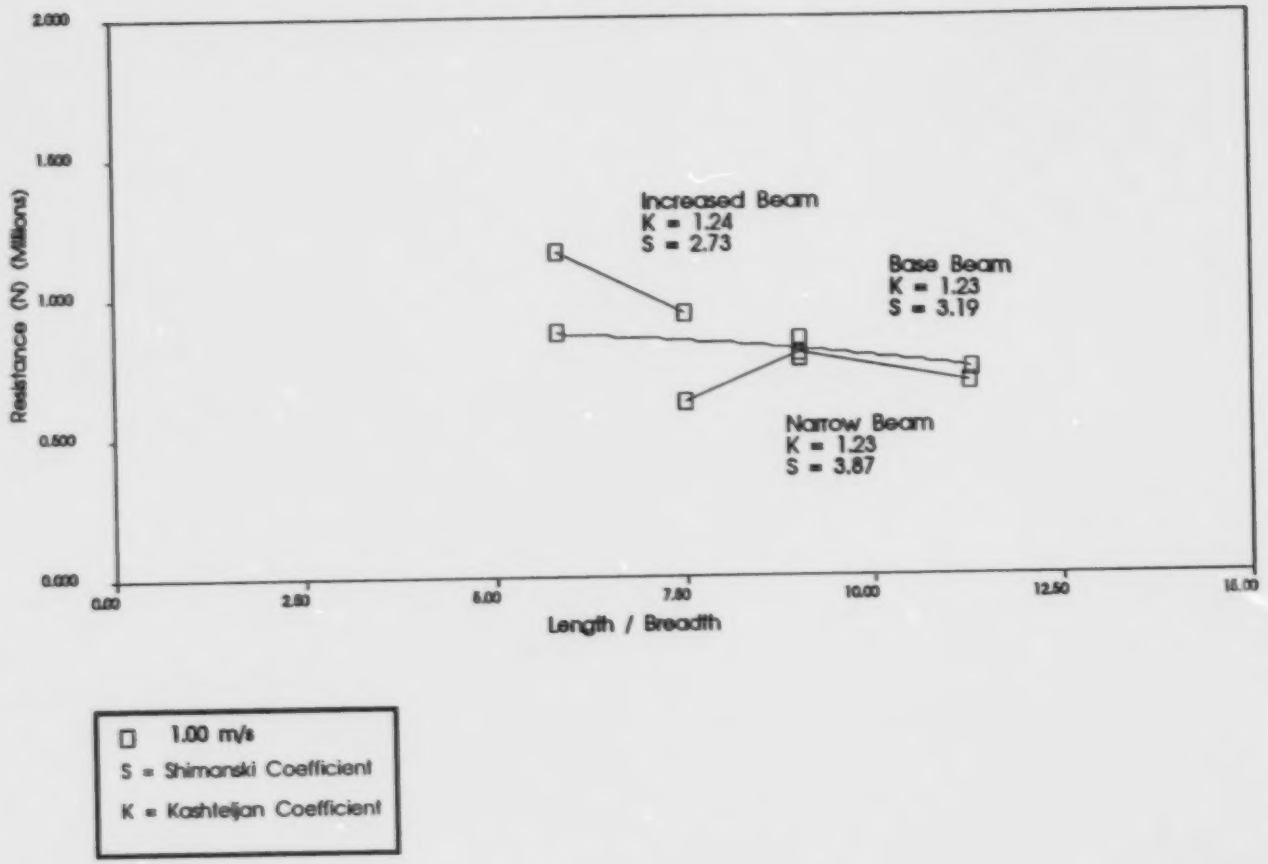


Figure 17
Resistance vs L/B Ratio for the ARCTIC Hull
Form with Displacement Normalised to 30,000 tonnes

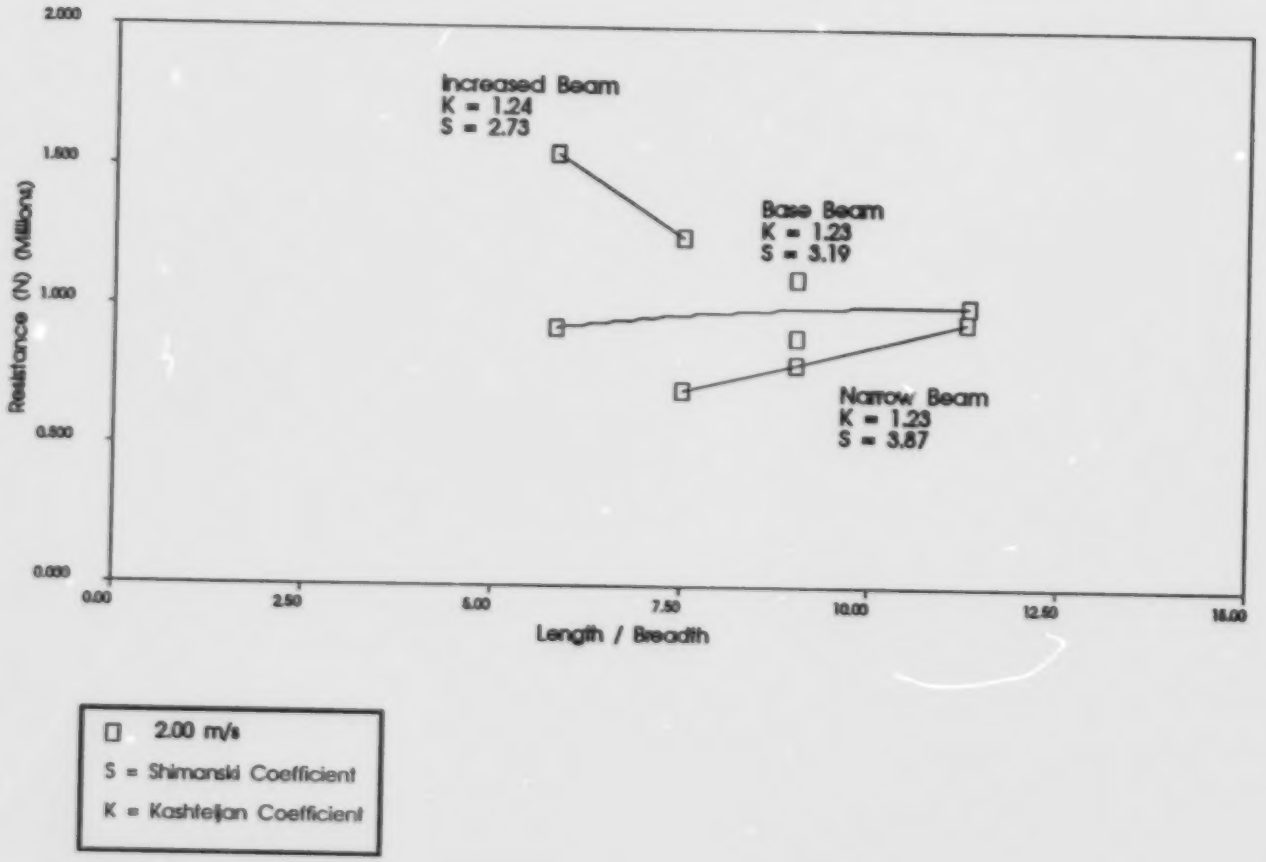


Figure 18
Resistance vs L/B Ratio for the ARCTIC Hull
Form with Displacement Normalised to 30,000 tonnes

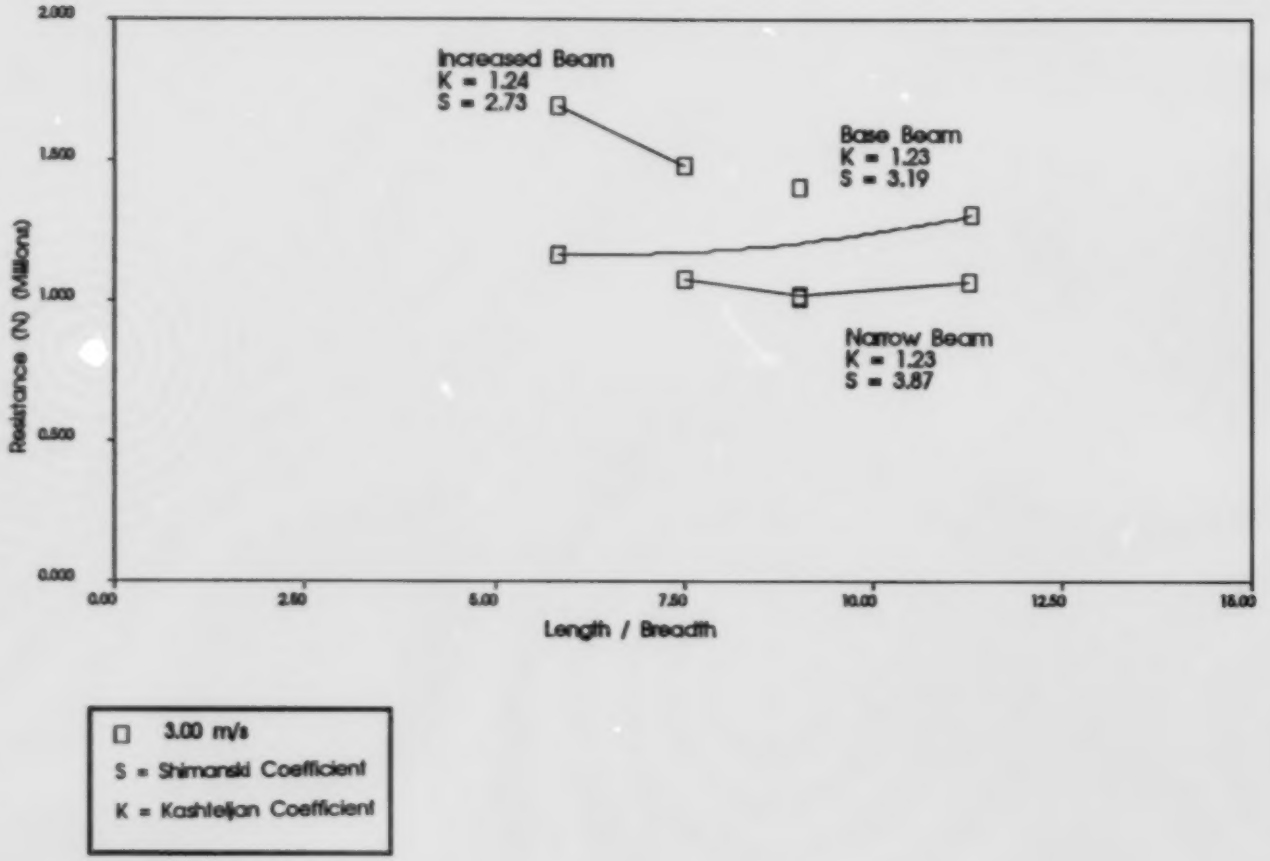


Figure 19 illustrates the normalised resistance data for the Arctic test series plotted against Shimanski coefficient. The Beam variation tests on the Arctic resulted in a range of models with constant Kashteljan coefficient (1.23) and variable Shimanski coefficient. It can be seen from the figure that the relationship between resistance and Kashteljan coefficient for the Arctic series is fairly consistent with a gradual decrease in resistance, at both 1.0 and 3.0 m/sec, as the Shimanski coefficient increases. This is reasonable and consistent with the generally accepted influence of the Shimanski coefficient and relates to Figures 16 and 18 in which the different bow forms associated with the increased and decreased beams yielded a range of resistance values.

A second set of model tests, conducted with the R-Class type of bow were tested over a range of model scales, resulted in similar Kashteljan coefficients. The R-Class type of bow has been used on a number of different hulls. Figure 20 illustrates the range of normalised data from this series, including the R-Class hull. Again there is a correlation, particularly for the Rogers and Bernier models tested with the R-Class bow. However, the general trend is an increasing resistance with Shimanski coefficient. The speed dependency and the relationship between the Arctic test series and the R-Class tests are illustrated in Figures 21 and 22.

Figure 21 and 22 shows the low speed, 1.0 m/sec and 3.0 m/sec data from the Arctic and R-Class tests series. The upward trend of the R-Class data is evident although it may now be noted that it is only the actual R-Class hull data which does not generally conform to the ARCTIC downward trend. At lower speed the Rogers and Bernier data are marginally low but within reasonable experimental errors.

The Nordic and Louis were also tested with Melville type Bows. The Nordic had a Kashteljan coefficient of 1.27 and the Louis 1.26. These are similar to the values for the other Arctic bows and illustrated in Figure 23. It may be noted that although the Louis Melville Bow correlates well with the Arctic data set, the Nordic data does not conform so well.

Data from all the models analyzed are presented on Figures 24 and 25. In the case where there are multiple lengths and beams for the same Kashteljan or Shimanski coefficient then those hulls with the closest values to the remaining data have been selected. For example, the wide beam Arctic was tested at two L/B ratios, 7.52 and 5.85. Since both these models have the same Shimanski and Kashteljan coefficients it was elected to use the short ship configuration with an L/B of 5.85, as being the closest to the remaining data. The average L/B ratio of the data is 5.15.

Figure 19
Resistance vs Shimanski Coefficient
Hull Displacement Normalised to 30,000 tonnes
ARCTIC Hull Forms

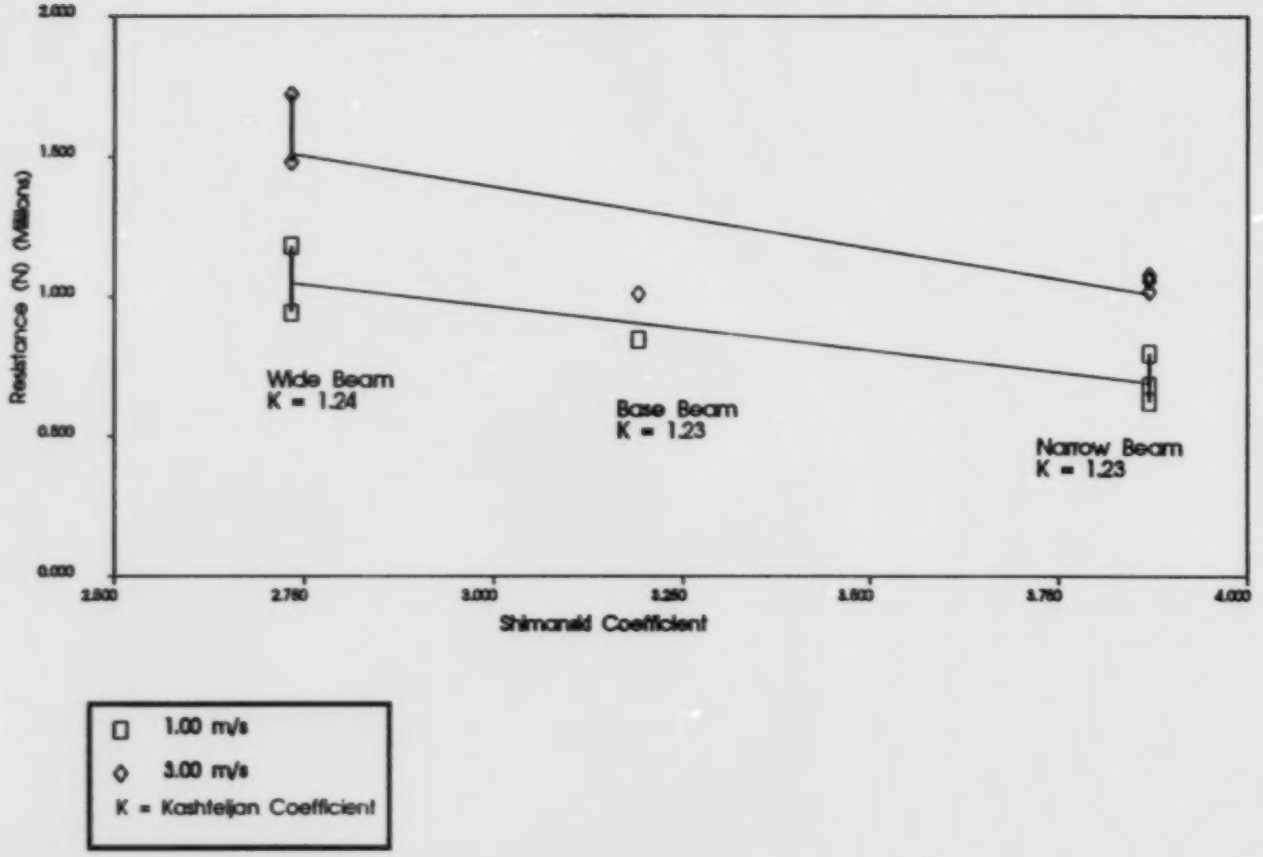


Figure 20
Resistance vs Shimanski Coefficient
Hull Displacement Normalised to 30,000 tonnes
R-Class Hull Forms

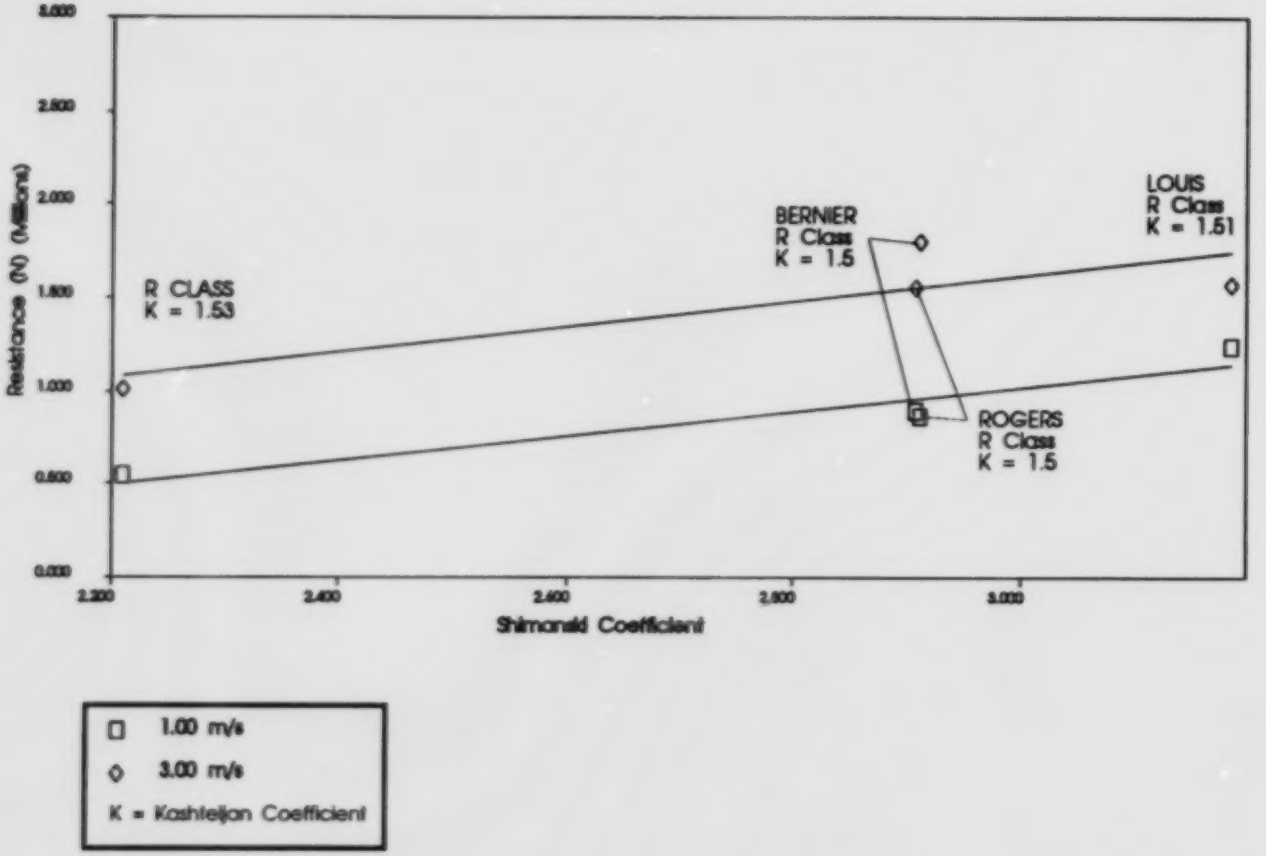


Figure 21
Resistance vs Shimanski Coefficient
Hull Displacement Normalised to 30,000 tonnes
ARCTIC and R-Class Series Data

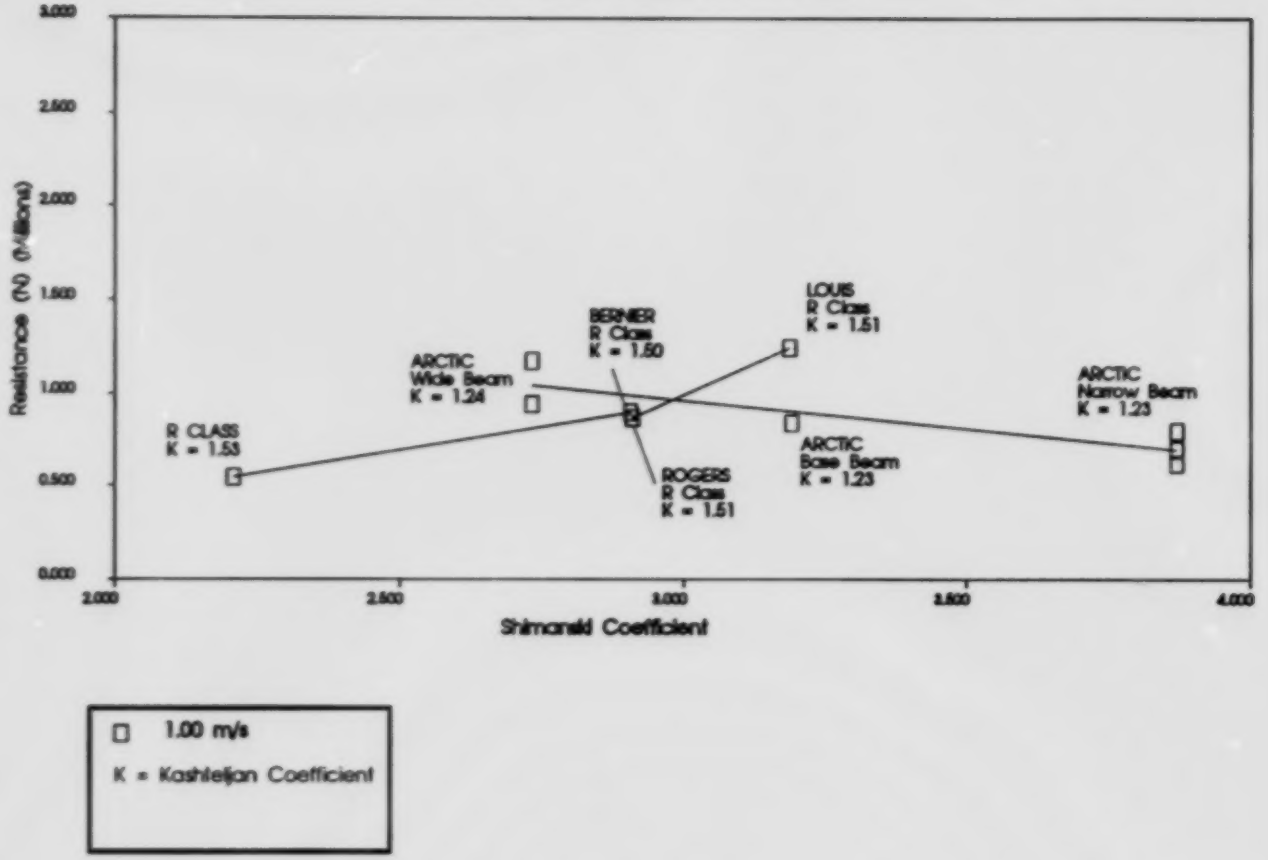


Figure 22
Resistance vs Shimanski Coefficient
Hull Displacement Normalised to 30,000 tonnes
ARCTIC and R-Class Series Data

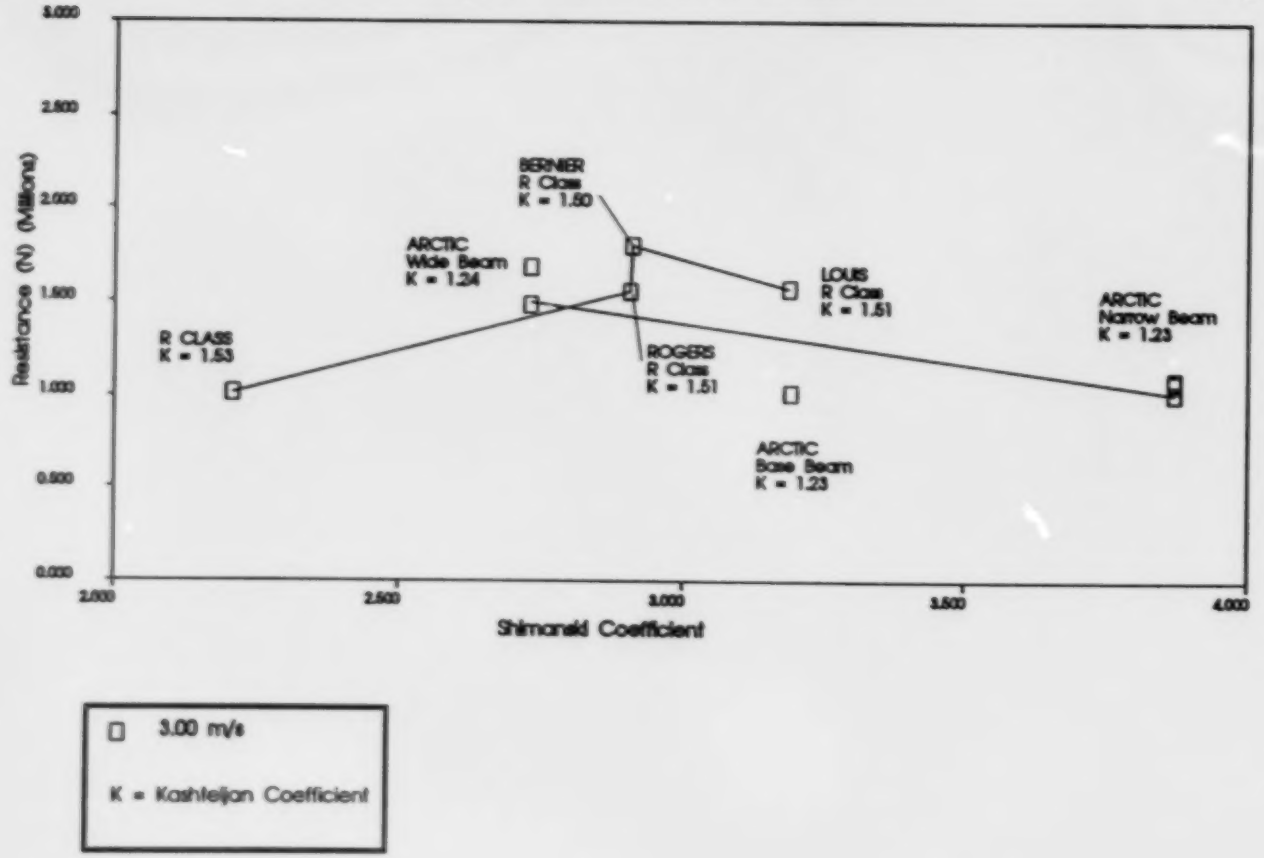


Figure 23
Resistance vs Shimanski Coefficient
Hull Displacement Normalised to 30,000 tonnes
ARCTIC, R-Class, Louis and NORDIC Series Data

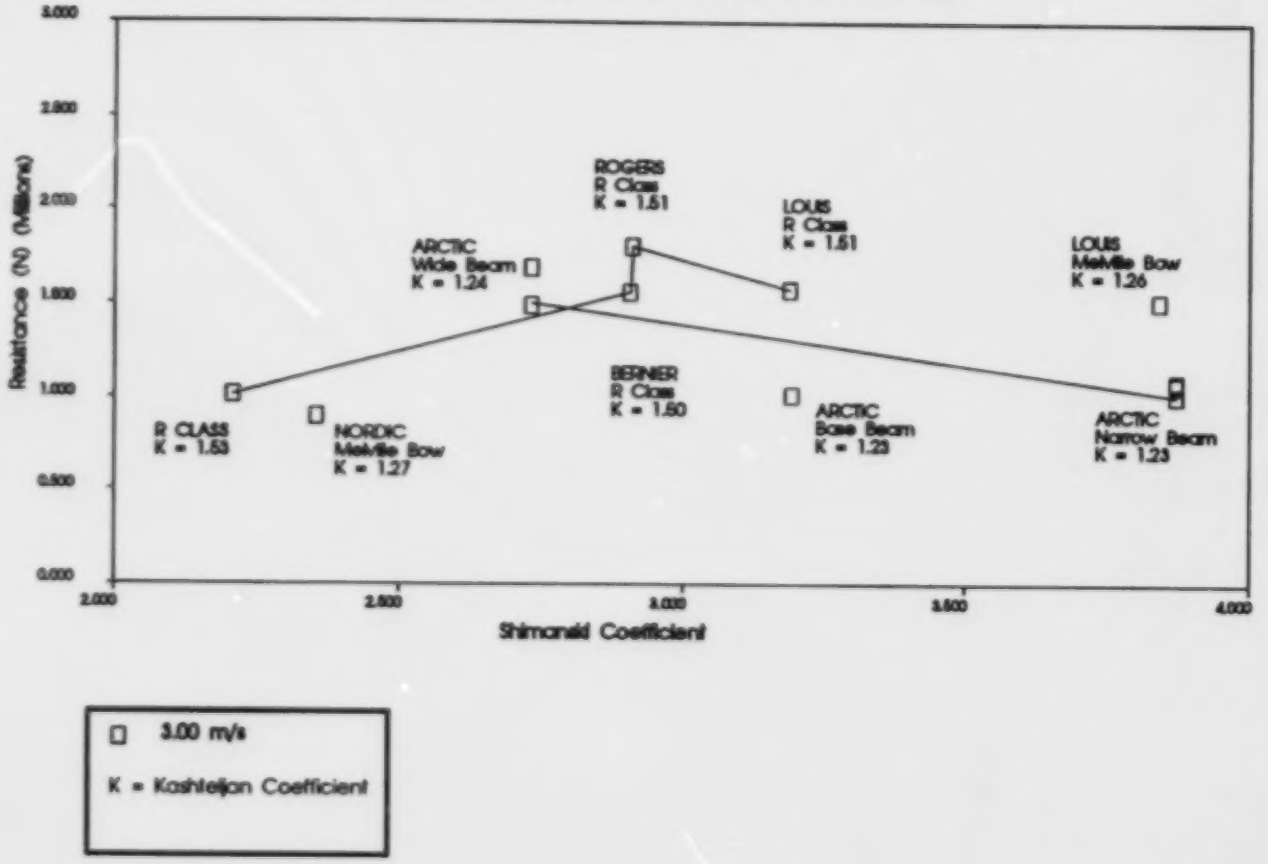


Figure 24
Resistance vs Shimanski Coefficient
Hull Displacement Normalised to 30,000 tonnes
Range of Ship Series Data

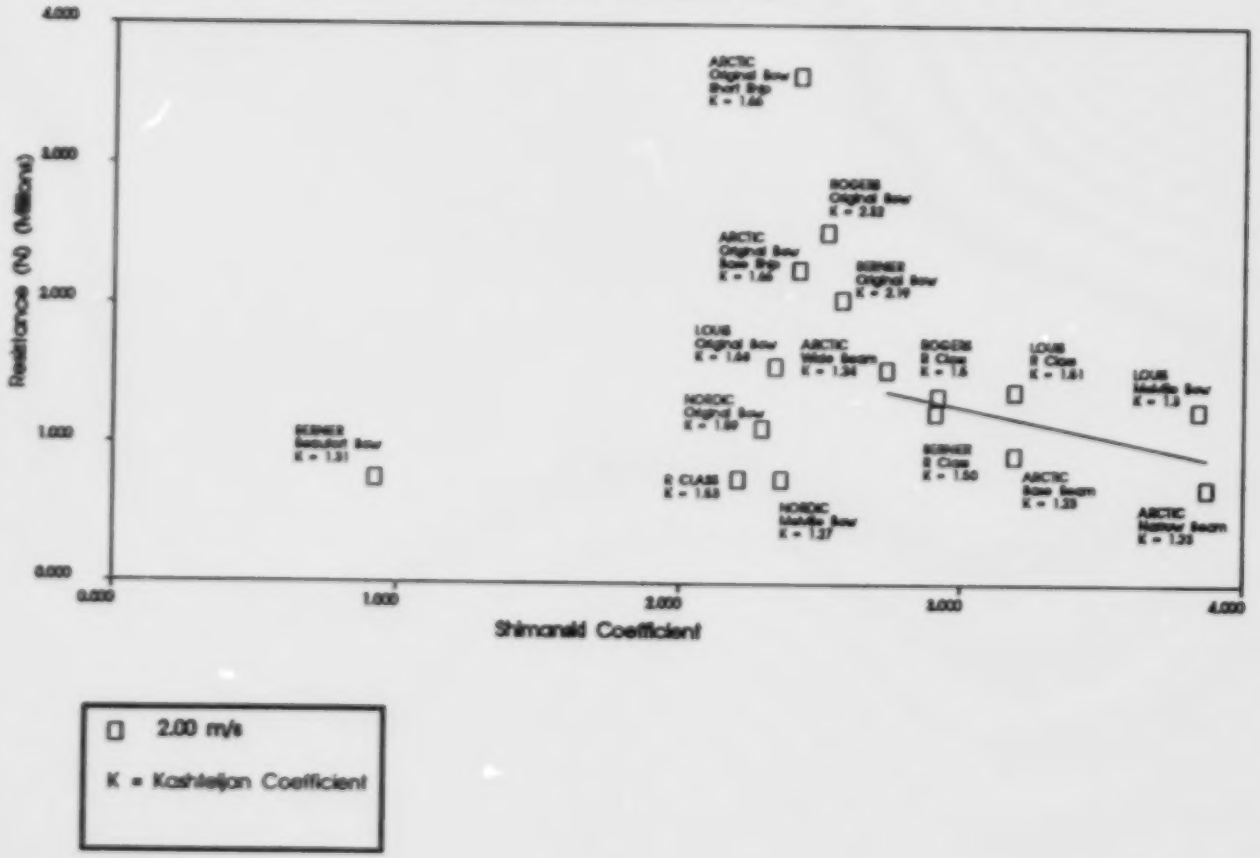
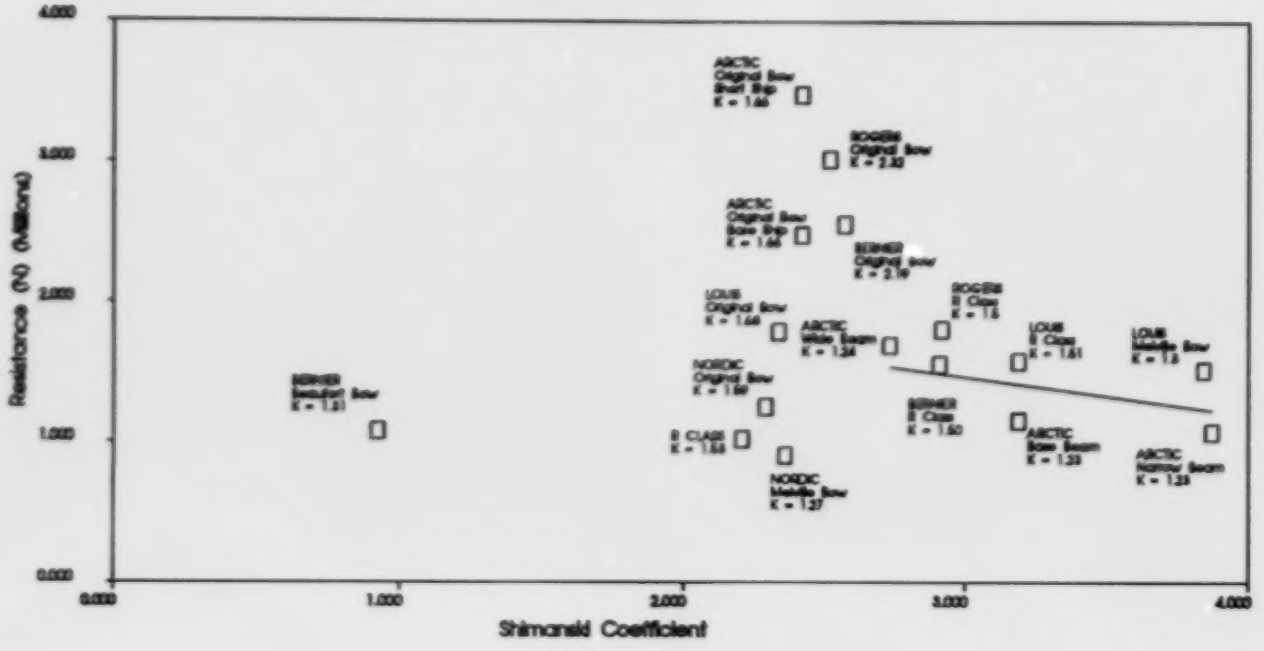

Resistance (N) (Millions)
4.000
3.000
2.000
1.000
0.000
0.000
1.000
2.000
3.000
4.000
Shimanski Coefficient
ARCTIC Original Bow Short Bop K = 1.66
ROGERS Original Bow K = 2.33
ARCTIC Original Bow Bow Bop K = 1.66
BERNER Original Bow K = 2.19
LOUIS Original Bow K = 1.66
ARCTIC Wide Beam K = 1.34
ROGERS E Class K = 1.5
LOUIS E Class K = 1.61
LOUIS Modified Bow K = 1.3
NORDIC Original Bow K = 1.60
BERNER Bendbulb Bow K = 1.31
E CLASS K = 1.65
BERNER E Class K = 1.50
ARCTIC Bow Beam K = 1.33
NORDIC Modified Bow K = 1.37
ARCTIC Narrow Beam K = 1.30
2.00 m/s
K = Kashiwajan Coefficient

Figure 25
Resistance vs Shimanski Coefficient
Hull Displacement Normalised to 30,000 tonnes
Range of Series Data



One exception to this is the original bow on the Arctic. The data from the base length model and the short model has been included. The reason for this is clear from the figures in which the original Arctic has a very high resistance. It is not clear that this is due to the model hull form or to a problem during model tests of this hull.

Figure 24 and 25 illustrate trends in the data of decreasing resistance with increasing Shimanski coefficient which is consistent with traditional beliefs. In those cases in which a similar hull shape is tested the relationship is quite strong. For example, the Melville bow shapes on the Arctic and Louis and the R-Class bow on the Louis, Bernier, and Rogers are consistent. Figure 26 illustrates the same data plotted as Resistance vs Kashteljan coefficient. The trend is again consistent with the traditional beliefs, namely that resistance increases with Kashteljan value. These relationship give confidence to the approach adopted by the analysis, to non-dimensionalize the data with displacement, despite some scatter in the data points.

In that context, the foregoing relationship between Resistance and Shimanski coefficient serves to explain the separation between the resistance lines found in the beam variation tests presented previously in Figure 17 and reproduced in Figure 27. In this figure, where all bows have the same Kashteljan value, the resistance lines for the increased and narrow beam results would tend to collapse along the base beam resistance line (as indicated by arrows) if all bows had also the same Shimanski values - an achievable design objective. This confirms the original conclusion of this research program that icebreaker resistance, whilst sensitive to bow geometry, is relatively insensitive to the overall hull length/breadth ratio. Such a conclusion offers icebreaker designers greater opportunities to optimize the resistance, manoeuvrability and even many aspects of hull strength and cost.

The further general conclusion that can be drawn from the foregoing figures and analysis is that the Kashteljan and Shimanski coefficients yield a relative measure of hull performance providing that they are compared to similar bow designs. In an attempt to quantify the sensitivities, Figure 28 illustrates the same data plotted on a basis of the reciprocal of Shimanski vs Kashteljan coefficients. Each of the hull forms are presented and the resistance at 2.0 m/s is shown on the figure. It can be seen that although there are individual groups of data that can be related, there are no consistent trends. As a result, although specific hull forms may be assessed in a qualitative fashion there is insufficient data for a quantitative analysis of the data.

The reason for the scatter of data are thought to be associated with three causes:

- The definition of the hull form using Kashteljan and Shimanski coefficients
- The friction coefficient recorded during the model tests
- Ice strength definition

Figure 26
Resistance vs Kashteljan Coefficient
Hull Displacement Normalised to 30,000 tonnes
Range of Ship Series Data

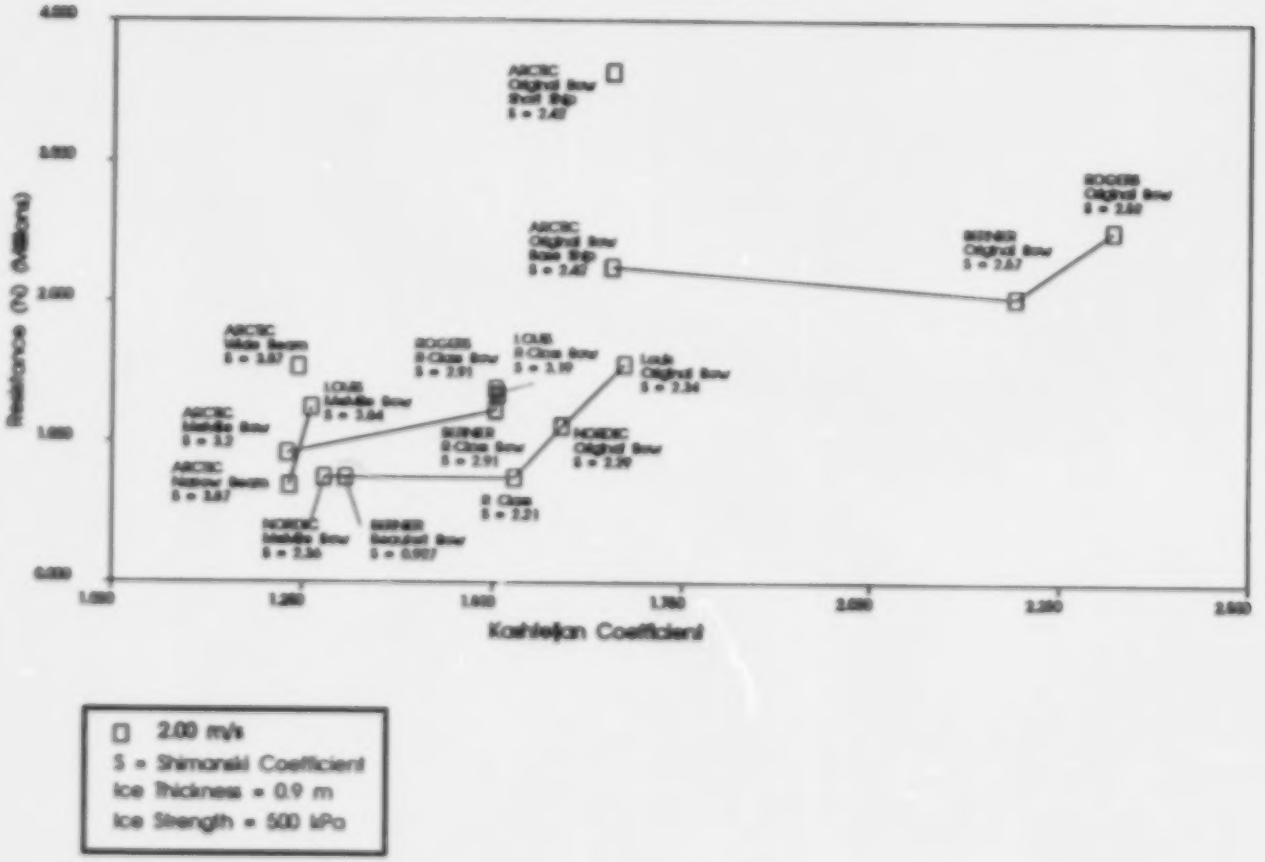


Figure 27
Resistance vs L/B Ratio for the ARCTIC Hull
Form with Displacement Normalised to 30,000 tonnes

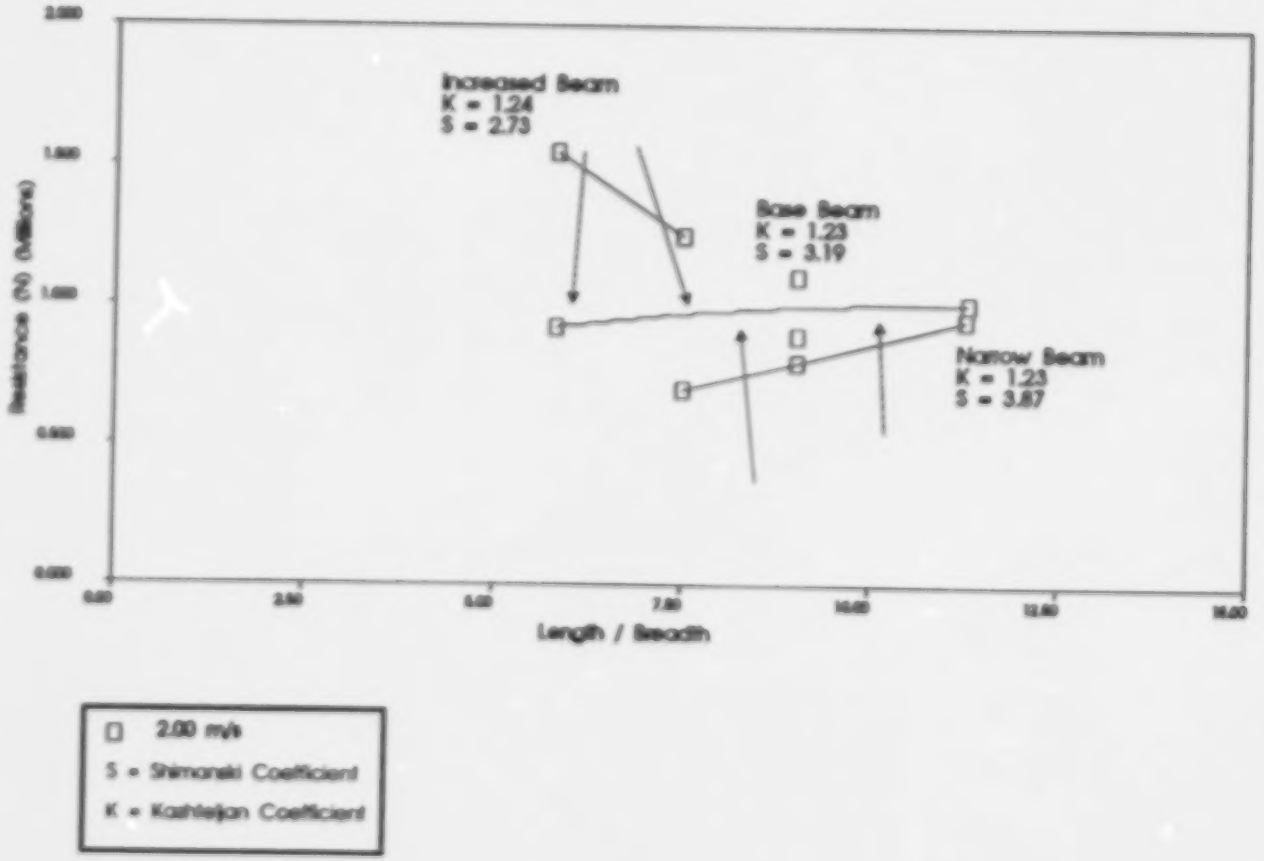
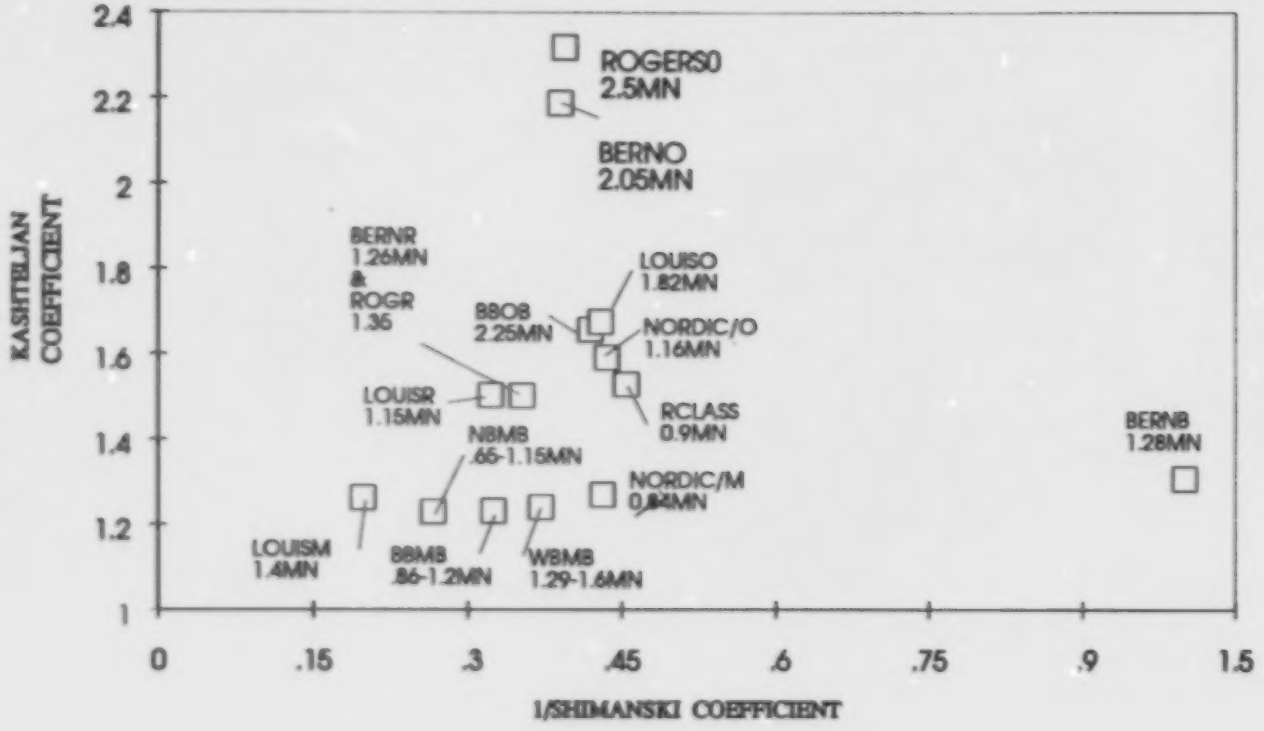


Figure 28
Kashteljan vs Shimanski Coefficient
Data Presented With Resistance at 2.0 m/sec



The Friction coefficient may have caused some of the scatter in the data. Currently only very approximate methods are used to correct for the friction and the tests analyzed covered a wide range. The existing panel method for evaluating friction relies on an identical paint surface on the model and on the test panel. This is not always possible and may result in errors. The ice test samples are also handled during the friction test experiment which may also cause differences between the ice in the tank interacting with the model and the test sample.

Ice strength, represented by flexural strength, is only measured in specific locations in the tank. Little information is available on the ice crushing and shearing strength. The influence of the strength on the resistance may be significant and, as noted in other reports to TDC, may influence different hull forms in different ways. A device called the INDEXER has been developed to measure the mechanical properties of the ice but has not yet been used extensively during model tests.

The definition of the bow form is believed to be the major cause of scatter and differences between the data sets. The Kashteljan and Shimanski coefficients are only general descriptions of the bow form and do not offer the specific detailed representation of form that is necessary to define the more complex shapes currently being developed. In that respect, it is evident that the subject of geometrical indices of bow shape should be further researched to provide a more precise measure of icebreaking resistance over a wide range of bow forms.

Another way of representing the data is to review a plot of Shimanski vs Kashteljan coefficient. This is illustrated in Figure 27. Each of the hull forms are presented and the resistance at 2.0 m/sec is shown on the figure. It can be seen that although there are individual groups of data that can be related, there are no consistent trends. As a result, although specific hull forms may be assessed in a qualitative fashion there is insufficient data for a quantitative analysis of the data.

5.0 Conclusions

A review of model tests has been completed. The tests illustrate the influence of ship beam, length, L/B and hull form on ice breaker resistance. A total of 23 hulls were analyzed and presented in the form of resistance vs Kashteljan and Shimanski coefficient. The analysis has shown that the performance of a hull can be related to the two coefficients but with only limited confidence and only in a comparative sense between two similar types of hull form.

The results from earlier phases of the work have been qualitatively rationalised with respect to the Kashteljan and Shimanski coefficients. However, although trends were identified in the range of data reviewed, there was not sufficient evidence to quantitatively define the relationship between hull resistance and these hull form coefficients.

Notwithstanding the difficulties associated with establishing precise bowform coefficients, the research carried out in the three phases of the Icebreaker Midbody Resistance program has confirmed that resistance, while sensitive to bow geometry, is relatively insensitive to overall length to breadth ratio of the hull. This conclusion permits greater freedom of choice of overall hullform proportions in the design of icebreakers in seeking to optimise total performance.

A sophisticated computer program DATAN was also developed that will permit researchers and scientists to analyze the results from model tests in ice quickly and with minimum training. The creation of DATAN has permitted the analysis of model test data from IMD that was formerly not possible without training and access to the IMD VAX computer.

6.0 Recommendations

The recommendations resulting from this work are;

- The definition of icebreaker hull forms must be improved to include the influence of the shape of the bow along the waterline. The Kashteljan and Shimanski coefficients are not sufficiently rigorous to permit design decisions to be made on their absolute values.

- The DATAN program should be integrated into the IMD ice carriage data acquisition system so that model test results can be immediately analyzed and reviewed to identify problems while the ice is still available for additional testing.

- Additional models, already tested at IMD, should be included in the analysis.

REFERENCES

1. **Melville Shipping Ltd.;** Ice/Hull Friction Coefficient Study, Main Report, 1987, TP 8915E

2. **Melville Shipping Ltd.;** Effect of Parallel Midbody on the Resistance of Ships in Level Ice, 1988, TP 9242E

3. **Melville Shipping Ltd.;** Icebreaking Midbody Resistance - Phase II: Beam Variation, 1990, TP 10161E

4. **Jones, S.J. et al.;** Ice Tank Model Test Methods at IMD, IMD Report LM-AVR, May 1987

5. **Timco, EG/AD/S;** A New Type of Model Ice for Refrigerated Towing Tanks, Cold Regions Science and Technology, October 1985

6. **Melville Shipping Ltd.;** Redesign of the M.V. ARCTIC Bow - Bow Design and Model Testing, Transportation Development Centre, TP 5456E, November 1984

7. **Melville Shipping Ltd.;** Redesign of the M.V. ARCTIC Bow - Additional Model Tests at HSVA and WARC, Transportation Development Centre, TP 5812E, May 1985

8. **Colbourne, B.J.;** 1989 PhD Thesis, Memorial University of Newfoundland.

9. **Melville Shipping Ltd.;** Ice Strength INDEXER Phase III, Transportation Development Centre, TP 10486E, March 1990

APPENDIX 1

DATAN Software Manual

DATAN

- Data Analysis for Level Ice Resistance Tests -
- Software Manual -

- Version 1.0 -

Prepared for
Transportation Development Centre
Policy Coordination Group
Transport Canada

by
Melville Software
Ottawa
K1R 7S8

October 1991

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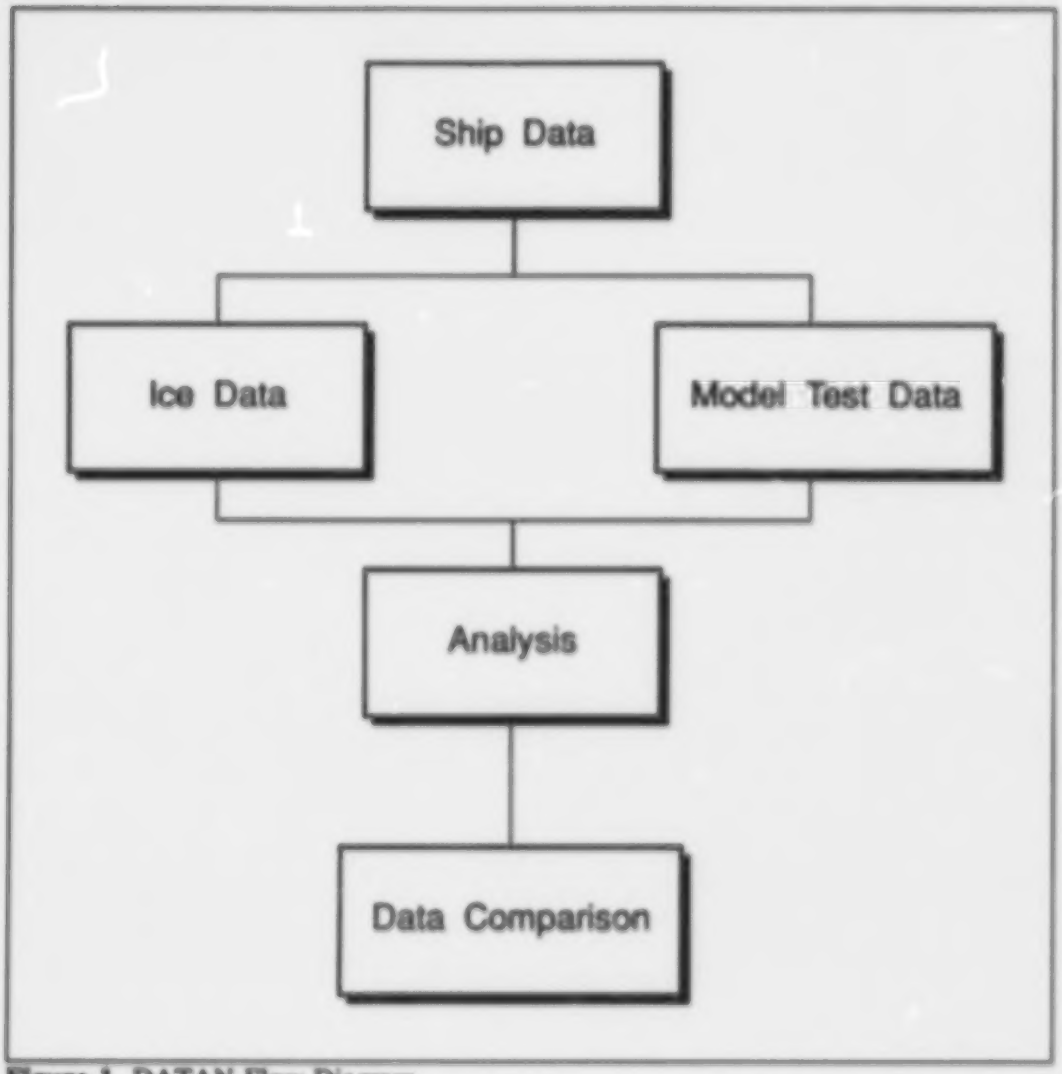

Figure 1 DATAN Flow Diagram

1.0 Preface

The DATAN computer program is an interactive user friendly analysis program designed for use in the interpretation, normalization and presentation of data from physical model resistance testing in level ice. A flow diagram of the program is shown in Figure 1.

The program is divided into five primary components:

- Ship Data
- Ice Data
- Model Test Data
- Analysis
- Data Comparison

The "**Ship Data**" component defines the model being tested in terms of its physical dimensions and features. This section also includes a scaling feature that permits you to assign a scale to the model to check full scale values.

The "**Ice Data**" component defines the mechanical and physical ice properties of the ice as they were recorded during the model tests. The ice properties are time dependent and plots of strength vs. time can be plotted to evaluate tempering features of the ice sheet.

The "**Model Test Data**" component automatically analyzes the data by selecting time segments based on predefined criteria. The resistance is then displayed as a function of speed. The analysis is also interactive so you can correct or modify the data sets for any anomalies.

The "**Analysis**" component permits you to define the type of correction or normalization that you want on the data. This includes both dimensional and non-dimensional analysis. The dimensional analysis for ice strength corrections is based on using data from the pre-sawn ice sheet. The correction for ice thickness is based on using data from other ice sheets conducted at a different thickness. The non-dimensional analysis is based on the Colbourne method (Colbourne 1989) which subdivides the resistance into breaking and clearing components.

The "**Comparison of Data**" component permits you to compare the results from different ships in the data base. A series of different relationships can be plotted including Resistance vs. Length, Breadth, L/B or Speed and Ice thickness vs. Speed.

The manual is divided into three sections;

- **Getting Started** — A description of how to load and start the application
- **Using DATAN** — A description of the standard Function keys and general program operation
- **DATAN** — A description of each component of DATAN and the assumptions used in its development.

2.0 Getting Started

2.1 System Requirements

To run the application you will require the following system as a minimum:

- DATAN Software.
- IBM PC/XT/AT/286 compatible or equivalent
- EGA or VGA display.
- MS-DOS 3.0 or higher.

2.2 Installation

The package which contains this manual should include at least one floppy disk, labelled DATAN. The first disk includes the main program and subsequent discs contain the program data files.

DATAN should be installed on the C:\ drive of your computer (to install the program on another drive, D or E, replace all occurrences of C: with the appropriate drive letter). The following instructions will guide you through this installation process. It is assumed that you are placing the program disks in the A:\ disk drive (if you are using the B:\ disk drive replace all occurrences of A:\ with B:\). All instructions that you should enter using the keyboard are displayed in **BOLD**.

- Start the computer and wait until the prompt indicates that you are in the root directory (i.e., C:\). If you are not in the root directory type **CD** to enter the root directory.

- Enter **MKDIR DATAN** to create a directory for the DATAN files.

- Place each floppy disk into the A:\ disk drive.

- Enter **COPY A:*.* C:\DATAN** to copy all files on the disk to the DATAN directory and follow any specific instructions on the disc.

This copies all the files to the DATAN directory. You can run the program by entering **CD \DATAN** followed by **DATAN**.

3.0 Using DATAN

3.1 Standard Conventions

The standard conventions that are adopted throughout the DATAN program have been designed to provide efficient use of the program and "on line" help at any point. These standard features are described in this section.

A list of function keys are displayed along the bottom of the screen. These keys can be used anywhere within the application.

Function Keys

<F1>: The <F1> key activates the help screens which exist throughout the program.

<F4>: The <F4> key activates the pop-up calculator.

ESC: The escape key closes the current window. An option may be given to save the data entered or to conduct some analysis, depending on the particular window. If the data is to be saved select 'Y' when prompted.

<F10>:Displays the current date and time until any other key is pressed.

Windows

A Window is a rectangular area which is placed on the screen to display additional program information or data entry fields. There may be one or many Windows displayed at any one time.

Although the program displays a variety of **Windows**, there are only a few items that should be remembered:

- To exit any Window press <ESC>.
- Leaving a Window will have no effect on the data that was displayed.

- To change data in the fields of a Window requires <ENTER> to be pressed after inputting the data. Using the cursor keys to move between fields will not overwrite existing data.

Menus

A menu is a rectangular area which is placed on the screen to display program operation functions. A selection may be made in a Menu by using the cursor keys to move the highlighted bar up or down to the desired item. That item is selected by pressing the <CURSOR RIGHT> key or the <ENTER> key.

If the Menu item has a character enclosed in square brackets [ ] then pressing this character key will select the item.

The user may move to the previous menu by selecting the e[X]it item in the Menu, pressing the <CURSOR LEFT> key or pressing the <ESC> key.

Lists

In addition to the Main Menus there are also **Lists**. Lists are similar to menus and windows and are located in data input screens where there are a finite number of choices, for example, a list of files, Yes/No answers or a list of program options. A selection can only be made from a list by pressing <ENTER> on the item or pressing the alphabetic key indicated in the square brackets. The <CURSOR LEFT> and <CURSOR RIGHT> keys move to the respective neighbouring fields.

NOTE: To activate the menu or list associated with a data field you must move to the particular field and press <ENTER>. You will not be able to input other data into a field associated with a list

---

Data Entry

Data can be entered in Windows where a flashing cursor rests in an input field. In these cases the input field will be to the right of the title and to the left of any units. To enter data in these zones type the desired entry using the keyboard and

press <ENTER>. If characters cannot be entered into a field it may be as a result of:

- Typing letters into a numeric field (i.e., The program does not allow letters into a field that is expecting numbers).
- Not using the correct format. For example, if the entry is set for 5 characters with two decimal places then only two digits may be entered to the left of the decimal point and two digits to the right of the decimal point.
- The data entry field is associated with a list.

Editing

There are a number of keystrokes that permit the editing of specific input values:

<F2>	Clears the value in the current field.
<F3>	Restores the original value in the current field.
<CURSOR LEFT>	Moves the cursor to the input field on the immediate left.
<CURSOR RIGHT>	Moves the cursor to the input field on the immediate right.
<CURSOR UP>	Moves the cursor to the input field directly above (using **<SHIFT TAB>** has the same result).
<CURSOR DOWN>	Moves the cursor to the input field directly below (using **<TAB>** has the same result).
<PAGE UP>	Moves the cursor to the first input field on the screen.
<PAGE DOWN>	Moves the cursor to the last input field on the screen.

There are a number of fields that can be calculated automatically by the program or input directly. These fields are shown as different colours in each screen.

<SHIFT F1> Recalculates the current field only.

<SHIFT F2> Recalculates all automatic fields on the screen.

The cursor keys, <PAGE UP>, <PAGE DOWN> or <ESC> will leave the input field without entering the value (or changing a value that was already present). To enter a value in a field, move the cursor to that field. The first key stroke of the new value will erase the original value and start the input of your new value. To reinstate the original value press <F3>. To edit one or more characters in an existing value use the <CURSOR LEFT> and <CURSOR RIGHT> keys, to position the flashing cursor and input the correct value. To clear the field for data entry press <F2>.

When editing character strings (not numeric values), the entry will not be cleared when typing in a new string. To clear the field press <F2>.

Help

The application has a comprehensive HELP feature that can be activated at any time in order to receive context-sensitive help. To activate the HELP option, move the cursor to the input position for which information is required and press the <F1> key. A **Window** will appear on the screen giving help on the type of variable or the correct procedure to follow at any time.

There are a number of specific windows that permit you to undertake standard tasks throughout the program. These are described below.

3.2 File Management

The file management window is used to load or save files. The window is illustrated in Figure 2 and activated by pressing <F5> for load and <F6> for save. There are three input fields. Press the <TAB> key to move up and down the three fields. The first allows you to select the directory in which your files are saved. The second field allows you to select the file within the directory you want to load or save. The third field is a filter. By selecting a mask for the file you can select which file extension will be displayed.

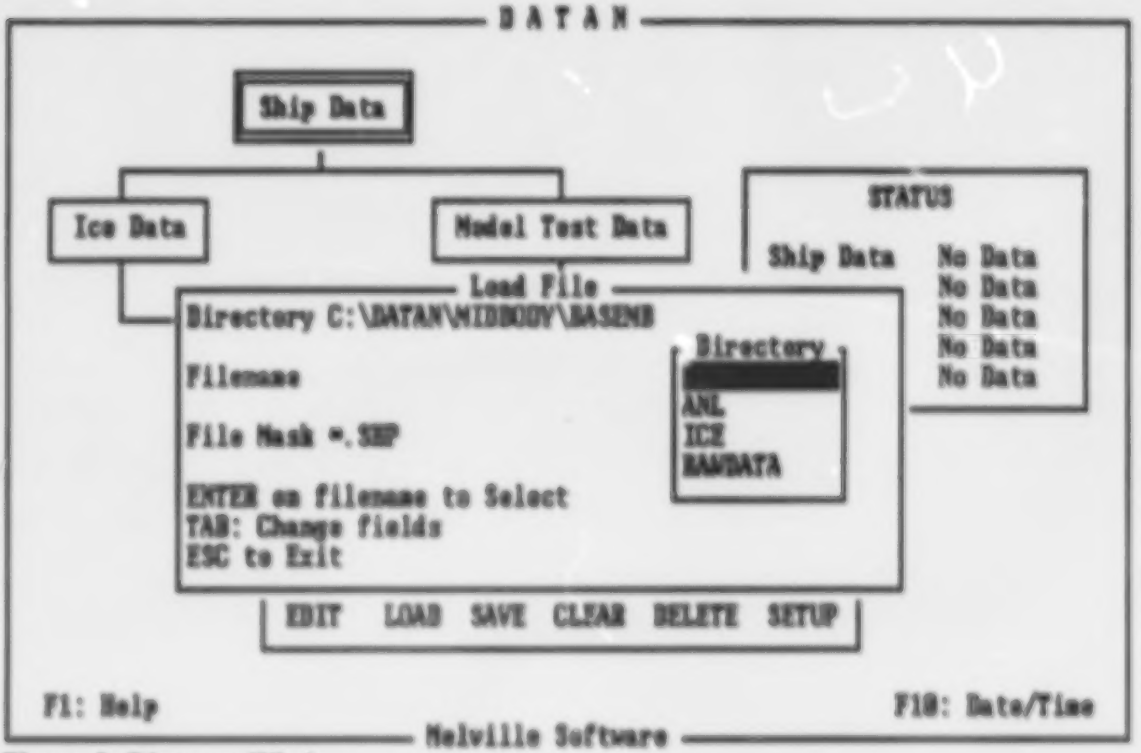

Figure 2 Directory Window

You will enter the window with the cursor on the file selection field. Files that exist in that directory and that comply with the mask in the third field can be activated by pressing the <TAB> key and will be presented in a pop-up list. Pressing <TAB> or <CURSOR LEFT> will delete the list and permit you to enter a file name manually. Pressing <TAB> again will move you to the Directory list.

The Directory list has the same format as the file list. As you enter the field a list of available sub-directories will be presented. The current directory is displayed in the field. Moving the highlight with the cursor keys and pressing <ENTER> permits you to move around in the directories of your computer. The [..] entry at the top of the directory list permits you to move up one level in the directory hierarchy. Pressing <TAB> or <CURSOR LEFT> will delete the list and permit you to enter a directory name manually. For example, if you want to read data from a floppy disk in your A:\ drive you would move to the directory field, press <TAB> or <CURSOR LEFT> and enter A:. This will move the directory hierarchy to the A: disk drive and list the directories.

The third field permits you to filter the files presented in the pop-up list. This is done with a "*" and a "?". The "*" notation is used to denote any string of letters or numbers. The "?" notation is used to denote any single letter or number. For example a filter "*.*" will list all files in the directory, *.SHP will list all files with an extension "SHP". Using the "?" allows you to be more selective with the filter, for example "*.??P" will list all the files in the directory that have an extension ending in "P". Similarly "?A?.* will list all files in the directory that have three characters in the file name with the middle letter "A" and any extension.

If you select a filter that does not correspond to any files in that directory you will be given an error message, press the space bar to re-edit the filter or <ESC> to close the window.

The program will remember which directory was last used to load or save files. This will be presented as a default. However, if this directory no longer exists, you will not be presented with a list in the directory selection field. To correct this, manually edit the directory field with any exiting directory. This will reactivate the directory list and permit you to use the window.

There will be a substantial number of files in the DATAN program made up from a number of file types and the data base of tested ships. To maintain some organization it is recommended that at least two directories are created under DATAN. The first "SHIPS" will contain the "Ship Files" from all the ships tested. The second will contain all the raw data and analysis files from each ship. In the case of the ARCTIC there have been a number of parametric variations so the existing ship is in a directory called BB_BL_MB. BB stands for Base Beam, BL stands for Base Length and MB stands for Melville Bow. The details of the existing ARCTIC model are defined in the "Ship File" and will be stored in a file called, C:\DATAN\SHIPS\BBBLMB.SHP. Results from the model tests will be in a directory called C:\DATAN\BBBLMB. The different file types are:

*.OWT	Open Water and Thrust Values for the Ship. These should be placed in the C:\DATAN\SHIPS directory. There will only be one *.OWT file per ship model tested.
*.SHP	Definition of the Ship Particulars. These should be placed in the C:\DATAN\SHIPS directory. There will only be one *.SHP file per ship model tested.
*.ICE	Definition of the Ice Data. These should be placed in the C:\DATAN\DATA directory where "DATA"

is the ship identifier. There will be one *.ICE file for each test, so they should be called, for example, Test1.ICE, Test2.ICE, etc. or ARC01.ICE, ARC02.ICE, etc. for the ARCTIC model tests series.

*.D?? The raw data time series from the ice resistance tests. These should be placed in the C:\DATAN*DATA* directory where *"DATA"* is the ship identifier. There may be a number of *.D?? files for each ice sheet. The only constraint on the definition of these files is that the first letter in the extension is "D". However, since a number of these files may exist for a single ice sheet it is recommended that the file name reflect the ice sheet number and the extension reflect the test number within that ice sheet. Therefore, for a series of tests on the same model, they could be called ARCTIC_1.D01, ARCTIC_1.D02 etc. for different tests in the first ice sheet and ARCTIC_2.D01, ARCTIC_2.D02 etc. for tests in the second ice sheet.

*.L?? The selected level ice resistance taken from the raw time series data. These should be placed in the C:\DATAN*DATA* directory where *"DATA"* is the ship identifier. There will usually be only one of these files for each test. The only constraint on the definition of these files is that the first letter in the extension is "L".

*.P?? The selected pre-sawn ice resistance taken from the raw time series data. These should be placed in the C:\DATAN*DATA* directory where *"DATA"* is the ship identifier. There will usually be only one of these files for each test. The only constraint on the definition of these files is that the first letter in the extension is "P".

*.ANL	These files store the setup of the Analysis screen. There can be as many of these files as you want. They should be placed in the C:\DATAN*DATA* directory where *"DATA"* is the ship identifier.
*.C??	The corrected data from the Analysis screen. These should be placed in the C:\DATAN*DATA* directory where *"DATA"* is the ship identifier. There will usually be only one of these files for each test. The only constraint on the definition of these files is that the first letter in the extension is "C".
*.CMP	These files store the setup of the Comparison screen. There can be as many of these files as you want. They should be placed in the C:\DATAN*DATA* directory where *"DATA"* is the ship identifier.
*.CFG	This file contains the colour setup and directory default values that save automatically when you leave the program.

NOTE: To prevent accidental deletion you will not be permitted to save a *.L?? or *.P?? without first deleting the original file. You can do this with the <F8> key.

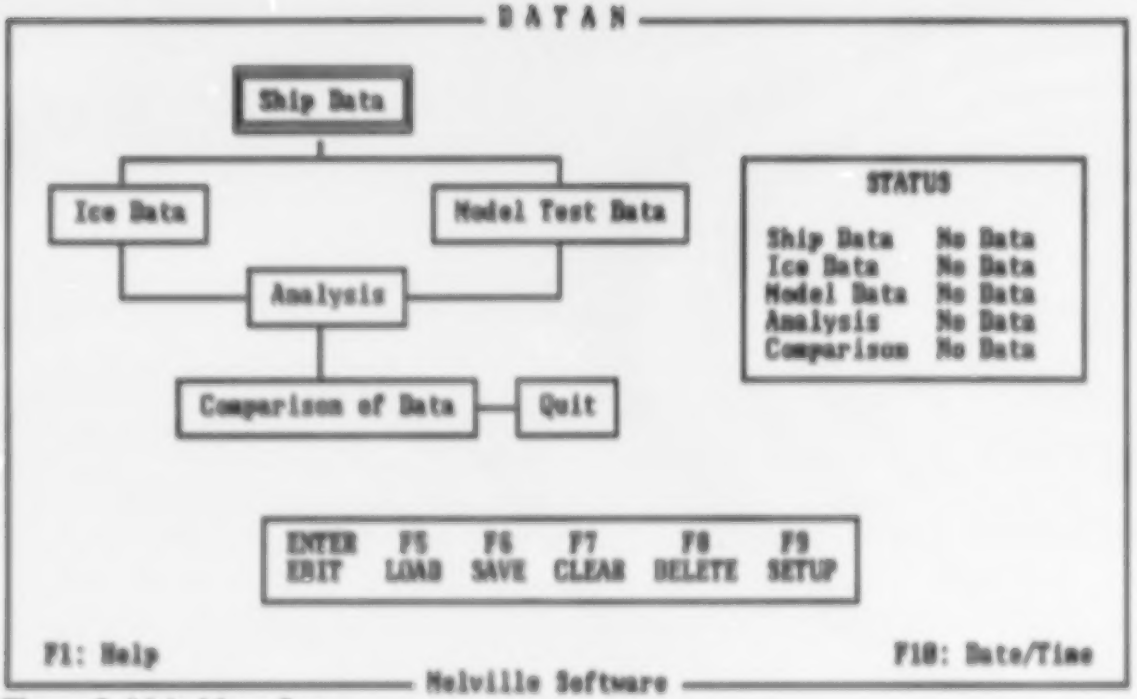

Figure 3 Main Menu Screen

4.0 DATAN

4.1 Overview

Figure 3 is the Main Menu screen that will appear after starting DATAN. There are three areas in the Main Menu screen. The first is a flow diagram which you will use to move around the program. The second is a "STATUS" box on the right of the screen, used as a reference to which files are loaded and the progress of the analysis. The third section, along the bottom of the screen is used for the standard function key operations. These are described in detail in "Using DATAN".

Each section is self contained and you must complete each section and save the appropriate files before progressing to the next screen. To move between different sections in the program use the cursor keys around the flow diagram and when you are on the required section press <ENTER>.

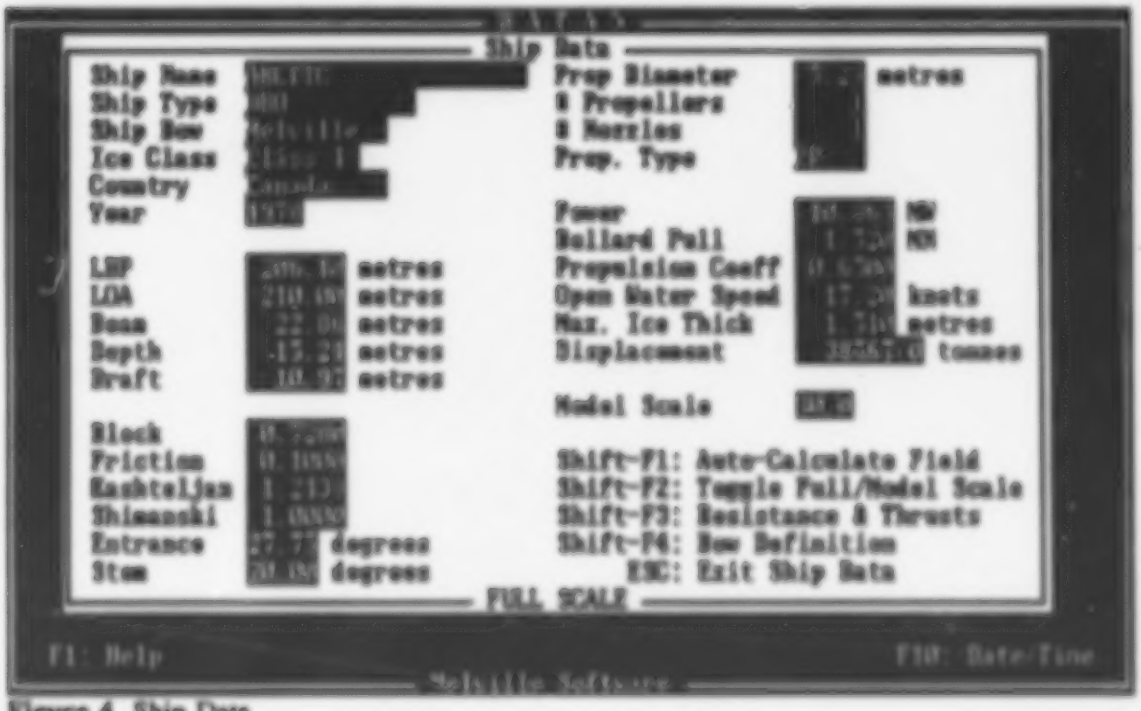

Figure 4 Ship Data

4.2 Ship Data

The ship data screen, Figure 4, consists of the necessary data to fully define the ship. There are two subordinate screens, the hull definition screen, that calculates the Kashteljan and Shimanski coefficients and the open water resistance and thrust curves for the subject vessel. Each variable is discussed below. The screen format is similar to other Ship Data screens in Melville Software programs. This is intentional to maintain consistency and, as a result, the screen contains information necessary for DATAN and data that is only used for reference purposes.

Ship Name — A name given by you to the hull for reference and identification.

Ship Type — There are four ship types, Icebreaker, Tanker, Bulk Carrier and OBO. Ship type is currently used in the program for reference purposes only.

Ship Bow	Description of the type of bow form for reference purposes.
Ice Class	A pop-up window lists the different regulatory ice classes currently in force. The ice class is currently used for reference only.
Country	The country of origin of the proposed ship, used for reference only.
Year	The year of construction of the proposed ship, used for reference only.
LBP	The length between perpendiculars of the subject hull.
LOA	The length overall of the subject hull.
Beam	Beam of the hull.
Depth	Depth of the hull.
Draft	Draft of the hull.
Block	Block Coefficient of the hull, defined as: $C_b = \left(\frac{LBP \cdot Beam \cdot Draft}{Displaced\ Volume} \right)$
Friction	Friction Coefficient of the subject hull.
Kashteljan Coefficient	Hull form coefficient, associated with the ice breaking resistance. The Kashteljan Coefficient can be input directly or calculated automatically by the "Ship Data" subwindows screen "Hull Definition".
Shimanski Coefficient	Hull form coefficient, associated with the ice clearing resistance. The Shimanski Coefficient can

	be input directly or calculated automatically by the "Ship Data" subordinate screen "Hull Definition".
Entrance	The entrance angle of the stem at the nominal waterline defined by the draft.
Stem	The stem angle at the nominal waterline defined by the draft.
Prop Diameter	Propeller Diameter.
# Propellers	Total number of propellers.
# Nozzles	Total number of nozzles.
Prop type	Option between Fixed or Controllable Pitch.
Power	Total installed propulsive power on the subject vessel.
Bollard Pull	Full power thrust of the propulsion system at zero speed.
Propulsion Coefficient	Propulsive coefficient of the subject hull.
Open Water Speed	The open water speed of the subject hull in knots.
Max. Ice Thick	The maximum ice thickness that can be broken by the subject hull at full power and two knots.
Displacement	The displacement of the subject hull in salt water. The displacement can be directly input or calculated from the block coefficient and hull dimensions.
Model Scale	The scale of the model. Full scale values can be entered by pressing <SHIFT-F2>.

In addition to the variables there are four function keys in the ship data screen:

<SHIFT-F1>	Activates the automatic calculation of variables on the screen. This is only used for the displacement.
<SHIFT-F2>	Toggles the screen between the full scale and model scale values.
<SHIFT-F3>	Activates the hull Resistance and Thrust subordinate screen.
<SHIFT-F4>	Activates the Bow Definition Screen.

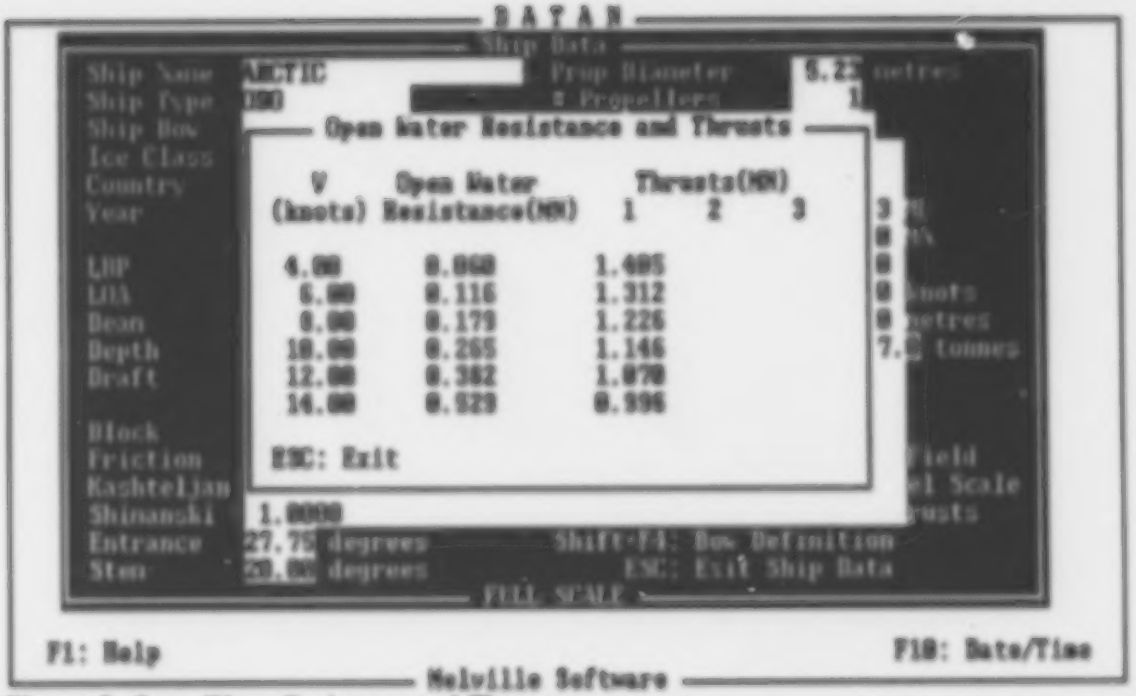

Figure 5 Open Water Resistance and Thrust

4.2.1 Open Water Resistance and Thrusts Screen

The Open Water Resistance and Thrusts screen, Figure 5, is a subordinate screen to the "Ship Data" screen and permits you to enter the full scale open water resistance and thrusts that will be used later in the Comparison section. The screen is a table that permits you to input a series of values for each parameter.

V	The speed of the hull in knots.
Open Water Resistance	The open water resistance of the hull.
Thrusts	Up to three values of thrust can be entered. The thrusts must be compatible to resistance and therefor includes any thrust deduction effects.

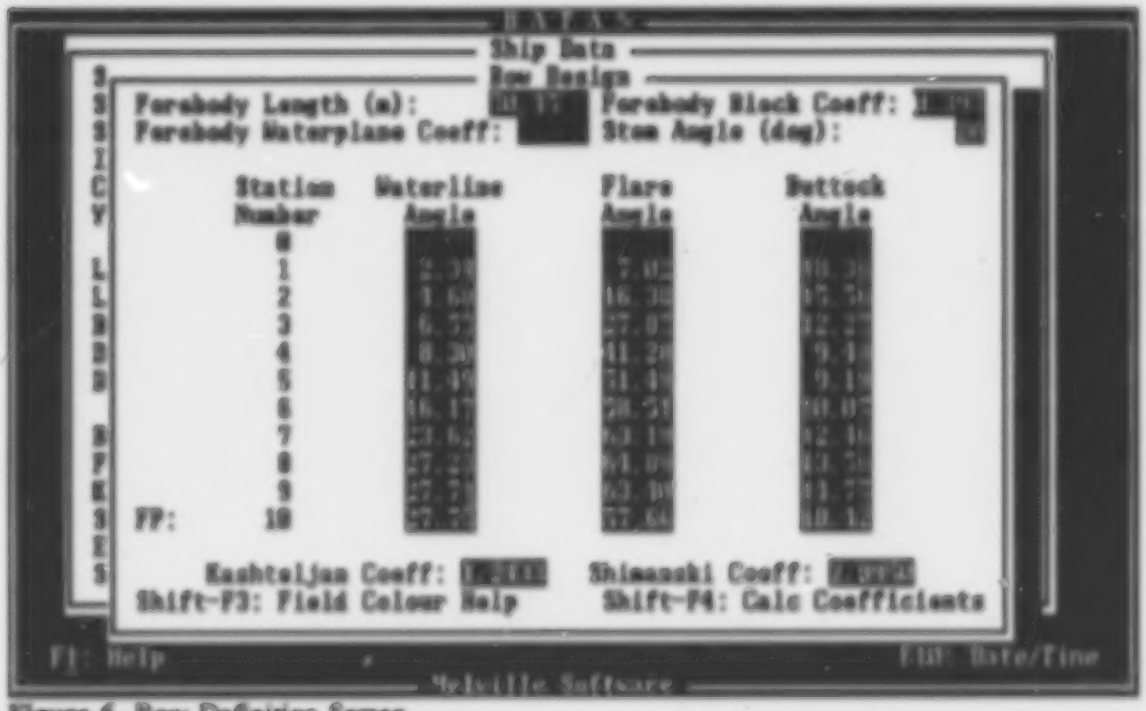

Figure 6 Bow Definition Screen

4.2.2 Bow Definition Screen

The bow definition screen, Figure 6, is a subordinate screen to the "Ship Data" screen and can be opened with <SHIFT-F4> from the Ship Data screen. Each variable is discussed below.

Forebody Length — The forebody length of the bow, defined as the length of the hull at the waterline forward of the maximum buttock line.

Forebody Block Coeff. — The forebody coefficient. This coefficient is used for information only.

Forebody Waterplane Coeff. — The Forebody water plane coefficient of the bow. This coefficient is used in the calculations for information only.

Stem Angle — The stem angle of the bow. This variable can only be changed in the "Ship Data" screen.

Station Number — Equal subdivisions of the forebody bow length.

Waterline Angle — The acute angle in the horizontal plane between the hull centre-line and hull tangent at the waterline at the nominal draft. The waterline angle is input directly.

Flare Angle — The acute angle in the transverse plane between vertical and the hull tangent at the waterline at the nominal draft. The flare angle can be calculated from the waterline and buttock angles or can be input directly.

Buttock Angle — The acute angle in the longitudinal plane between the horizontal and the hull tangent at the waterline. The buttock angle is calculated automatically from the waterline and flare angles or can be input directly.

Kashteljan Coeff. — The Kashteljan coefficient. Defined by the waterline and flare angles:

$$\textit{Kashteljan Coefficient} = \mu_k = 1 - \left(\frac{P_x}{P_z} \right)$$

where

$$P_x = \int_0^{l_f} \left(\frac{\tan^2\alpha \cdot \sqrt{1 + \tan^2\alpha}}{1 + \tan^2\alpha + \tan^2\beta} \right) dx$$

and

$$P_z = \int_0^{l_f} \left(\frac{\tan\alpha \cdot \tan\beta \cdot \sqrt{1 + \tan^2\alpha}}{1 + \tan^2\alpha + \tan^2\beta} \right) dx$$

where

α = Waterline angle
β = Flare angle
L_f = forebody Length

Shimanski Coeff.

$$\textit{Shimanski Coefficient} = \eta_s = \left(\frac{P_f}{P_a} \right)$$

where

$$P_f = \int_0^{L_f} \left(\frac{\tan\alpha \cdot \sqrt{1 + \tan^2\alpha}}{1 + \tan^2\alpha + \tan^2\beta} \right) dx$$

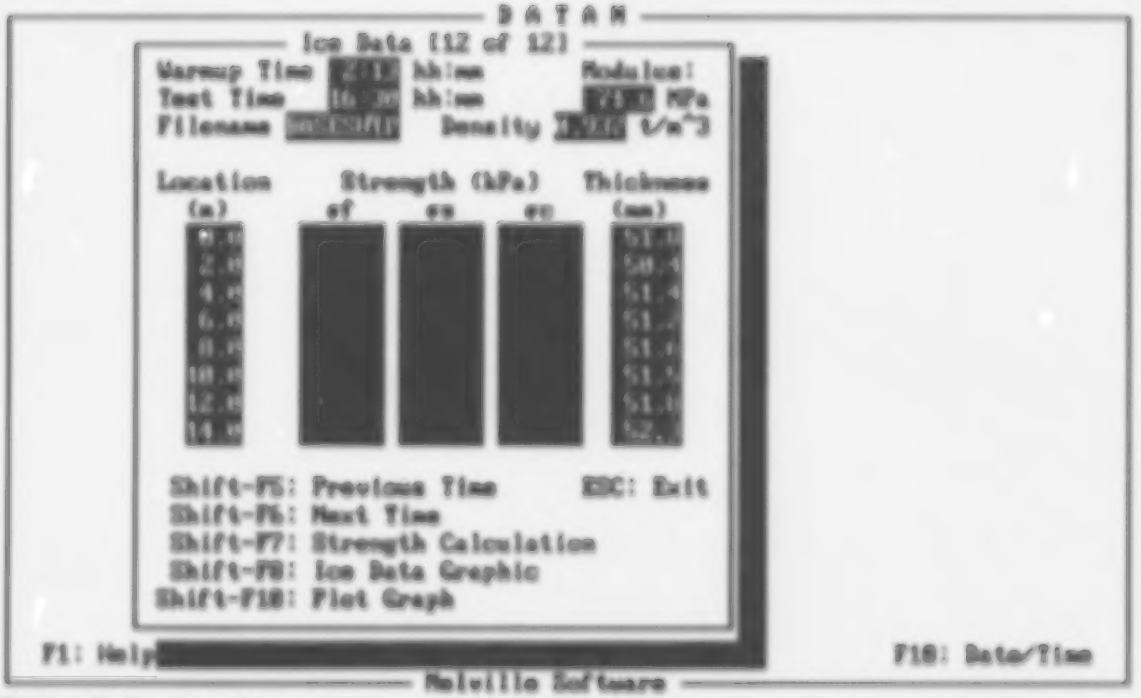

Figure 7 Ice Data Screen

4.3 Ice Data

The Ice Data screens, Figure 7, represent a series of time sequential steps through the ice tempering process. Each screen has four subordinate screens, three "Strength Calculation" screens, which allow you to input strength data, and the "Ice Data" graphic screen which plots the strength tempering curves. Each Ice Data screen has a number of input variables:

Warm up Time	Start time of ice sheet tempering. This value remains constant throughout the Ice Data sheets.
Test Time	Time of ice data test. Each Ice Data sheet will have its own unique time. Ice data sheets should be input chronologically.
Modulus	The Elastic Modulus of the ice sheet. Only one value is saved to represent the ice sheet.
Location	The location defaults to 2 m increments down the length of the ice tank. Other values can be input if required.
Strength	There are three strengths defined in the Ice Data screen; flexural strength, σ_b, shear strength, σ_s, and crushing strength, σ_c. These values can either be input manually or calculated as the mean from the original data through the Strength Calculation Screens.
Thickness	The thickness of the ice sheet.

In addition to the variables there are five function keys in the Ice Data screen:

<SHIFT-F5>	Changes the current Ice Data screen to the previous Ice Data screen.
<SHIFT-F6>	Changes the current Ice Data screen to the next Ice Data screen.

<SHIFT-F7>	Activates the Strength Calculation screen.
<SHIFT-F8>	Activates the Ice Data graphic display of flexural strength vs time.
<SHIFT -F10>	Plots the ice data graphic display of flexural strength vs time to a file.

4.3.1 Strength Calculation Screens

Selecting <SHIFT-F7> activates the strength calculation screens. Activating the screen in either the flexural, shearing or crushing columns will result in a different screen. These are described below.

a) Flexural Strength Calculation:

It is assumed that a conventional cantilever test has been conducted on a rectangle of ice cut in the ice sheet and loaded at its free end. The length (l), width (w) and thickness (h) of the cantilever are recorded together with the force necessary to break the ice, f. The flexural stress at failure is calculated for each cantilever together with the average stress. The stress is calculated based on the equation:

$$\sigma_f = \left(\frac{6 \cdot l \cdot f}{w \cdot h^2} \right)$$

where

σ_f = Flexural Strength
l = Cantilever length
w = Cantilever width
h = Ice thickness
f = Force to fracture cantilever

b) Shear Strength Calculation:

It is assumed that a shear test is conducted in which a cylindrical plunger is driven through an ice sample resting on a base with a corresponding hole beneath the plunger. An ice sample, the size of the plunger is driven through the hole in the base causing a shear failure around the perimeter of the hole. The diameter of the plunger (d), and thickness (h) of the sample are recorded together with the force necessary to fracture the ice, f. The individual shear stress at failure is calculated for each sample together with the average stress. The stress is calculated based on the equation:

$$\sigma_s = \left(\frac{f}{\pi \cdot d \cdot h} \right)$$

where

σ_s = Shear Strength
d = Plunger Diameter

c) Compressive Strength Calculation:

It is assumed that a uni-axial strength test is conducted in which an ice sample is crushed between two rubber platens. The width (w) and length (l) of the sample are recorded together with the force necessary to fracture the ice, f. The individual crushing stress at failure is calculated for each sample together with the average stress. The stress is calculated based on the equation:

$$\sigma_c = \left(\frac{f}{w \cdot l} \right)$$

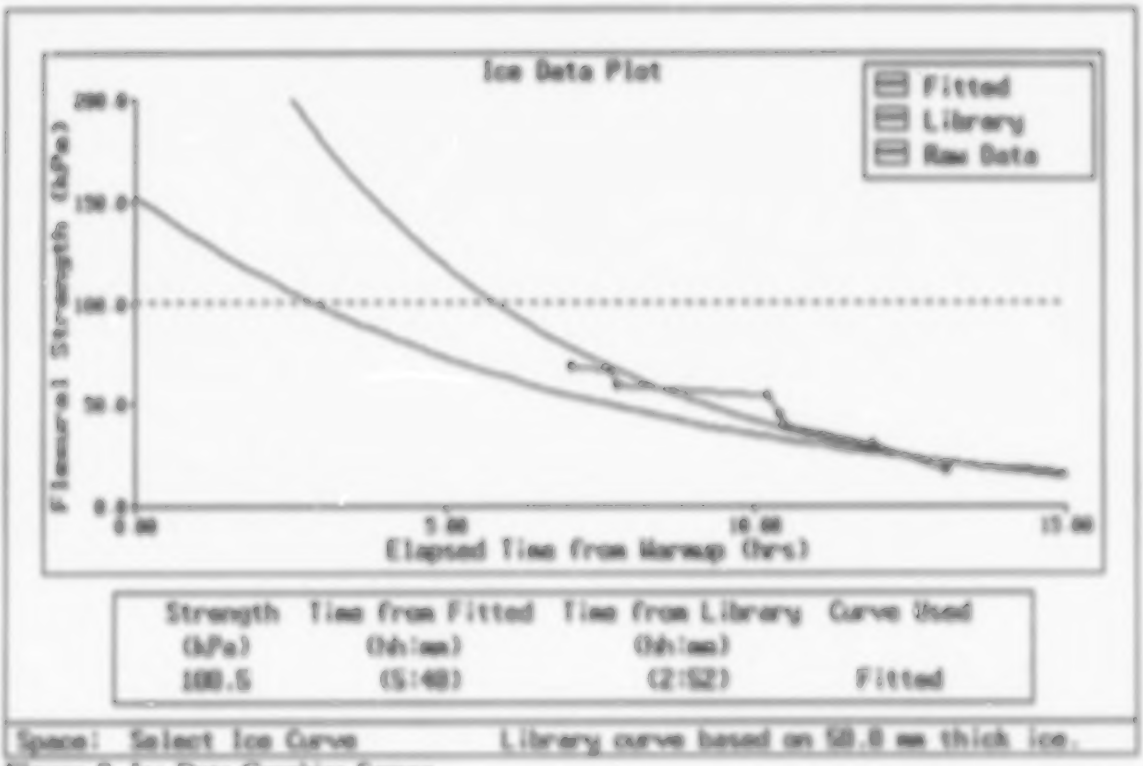

Figure 8 Ice Data Graphics Screen

4.3.2 Ice Data Graphics Screen

The ice graphic, Figure 8, is activated by pushing <SHIFT-F8>.

The graphic will display three curves, a least squares line through the specific data for the current test, a straight line curve between the actual data points recorded for the test and a curve taken from the library of past ice tests at the IMD ice tank. The curves are presented as ice strength vs. time. Using the <CURSOR UP> and <CURSOR DOWN> keys moves the dotted line on the graph which may be used to accurately determine the predicted ice strength at any time.

There are four fields below the graphic. The first presents the strength, in kilo pascals [kPa], of the ice at a specific time defined by the second and third field. The <SPACE BAR> permits you to toggle between the values of strength defined by the library curve and the current ice data curve. The fourth field defines which curve will be used in the subsequent analysis.

Figure 9 Model Test Data Screen

4.4 Model Test Data

The Model Test Data screen, Figure 9, controls the selection of samples from the time series data taken from the model tests. The screen has one graphic subwindows screen that displays x-y plots of the time series for manual changes to the data selection and two note-pad screens, one for your comments on the data and one for internal program comments.

The screen is divided into three sections. The upper section contains data pertinent to the overall test program. The middle section contains the data extracted from the time series data and the lower section contains the ice strength and thickness associated with the test series.

4.4.1 Test Information

The upper Test Information section contains:

Test File	The name of the Raw data file selected for analysis.
Test Time	The time at which the test was conducted.
Test Type	An option between either Level Ice or Pre-Sawn ice test.
Start Position	Each test may not start at the same position in the ice tank. This variable permits you to input the actual start position of the test in those cases when the start position is only defined in the raw data as the start of the test and subsequent positions must be integrated from the speed channel.
Channel	The subordinate screen to the Model Test Data screen displays x-y plots of the model tests. The "Channel" option permits you to select the channels you wish to display. Move to the first channel and press the <ENTER> key. This will activate a pop-up menu that lists the available channels. Move the highlight with the cursor keys and press <ENTER> to make a selection. You can select up to four plots to display at once.
Ship File	The name of the ship file associated with the test. This can be edited by pressing <ENTER> on the field which will activate the file load and directory window.
Ice File	The name of the Ice file associated with the test. This can be edited by pressing <ENTER> on the field which will activate the file load and directory window.

Figure 10 Selection of Channels in the Model Test Data Screen

4.4.2 Selecting Data

The middle section contains a scrolling table that presents the selected data sets from the raw data. To activate this section press <PAGE DOWN> while in the upper section of the Model Test Data screen. If the raw data set has not been analyzed then all the fields will be empty. To initiate the analysis press <ENTER> and a pop-up window will request you to select the channels that will be analyzed. Figure 10 illustrates the popup menu and note associated with the first channel selection.

NOTE: The analysis assumes that the first channel is Resistance, the second is Speed and the third is Position. A second pop-up window reminds you that these channels must be input in this order.

After you have selected the first three channels in the correct order, the remaining channels may be selected in any order. You will notice that by pressing the up and down cursor keys you are able to scroll vertically through the table although the first three fields are always displayed.

4.4.3 Time Series Analysis

The time series data is analysed automatically by the program and is activated by pressing <SHIFT-F5>. The automatic calculation involves moving through the speed channel data and selecting individual sets based on a number of criteria:

- Based on the speed channel the program runs through the time series data and selects the start and end of each constant speed. A "Constant Speed" is defined as one that remains constant to within 0.005 m/sec for longer than 5 seconds.

- The start point of the data sample or "Set", which will be used in the analysis, is calculated to be the start of the constant speed plus the time taken for the model to travel its own length at that speed.

- The end point of the data Set is calculated to be the point at which the speed is no longer constant.

- The duration of a Set, defined as the time between the start and end points, is then compared with the time taken for the model to move its own length.

- The time taken for the model to move its own length is a function of the model length (L) and speed (v)

$$Time \propto \frac{L}{v}$$

- If the length of the Set is greater than the time necessary for the model to move half its own length or 10 seconds then it is considered to be acceptable.

- If the length of the Set is less than the time necessary for the model to move half its length but more than a quarter of its length or is less than 10 seconds then the Set is considered to be acceptable, but flagged for future reference.

- If the length of the Set is less than the time necessary for the model to move a quarter of its then the Set is rejected.

- If the set is longer than 5 seconds and has an average speed lower than 0.005 m/sec the set is assigned to be "Zeros" that may be used for calibration.

Based on these definitions of the Set, statistical values are calculated and displayed in the table. The values presented are the Mean of the samples in each Set, the Maximum value in each Set, the Minimum value in each Set and the Standard Deviation in each Set.

After the analysis is complete you will be presented with the ice data screens. These are used to define the ice thickness data that should be used in the analysis. Use <SHIFT-F5> and <SHIFT-F6> to move through the time series screens until the correct time interval is displayed. Press the <ENTER> key to select the data.

Pressing the <CURSOR RIGHT> and <CURSOR LEFT> keys permit you to scroll horizontally through the data Sets.

NOTE: As you scroll horizontally through the Sets the number of each Set will be displayed above the table together with the total number of Sets.

4.4.4 Ice Data

The lower section of the screen contains the values of ice thickness and strength calculated from the ice data screens for that particular area of the ice sheet. These values are either automatically selected if there is a current ice data file or may be input manually if no ice files are available.

There are six function keys:

<SHIFT-F5>	Activates the automatic selection of the data Sets.
<SHIFT-F6>	Activates the Comments Window.
<SHIFT-F7>	Activates the Note Screen.
<SHIFT-F8>	Activates the manual review of the time series data.
<SHIFT-F9>	Use the first set as zeros and move it from this test.
<SHIFT-F10>	Export the data into a text file that can be used by EXCEL or LOTUS-123.

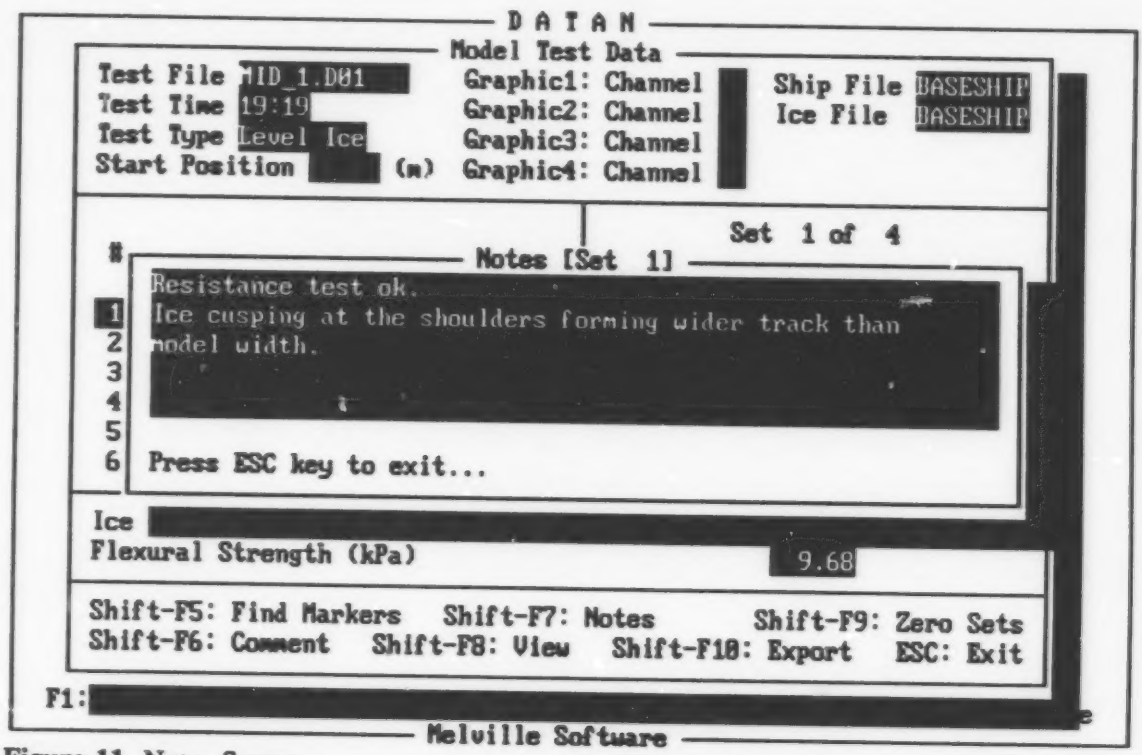

Figure 11 Notes Screen

4.4.5 Notes and Comments Screen

There are two "note-pad" screens within the DATAN application, the Note and Comment screens. Both provide extra information relevant to each data point. You can use the Note screen, Figure 11, for your own comments on the test data, for example any test anomalies that occurred or observations through the test. The Comments screen is reserved for computer generated comments that identify specific anomalies in the data or changes in the standard analysis procedure.

The Note Screen is activated by pressing <SHIFT-F7> in the Model Test Data screen. You can enter any comments or descriptions of the data point up to a maximum of five lines of sixty characters.

NOTE: Since the note screen is associated with a specific data point the screen can only be activated from the middle section of the Model Test Data screen and when there is data present in the columns representing the presence of a data set.

The Comments screen is a list of computer generated comments on the data set. If either notes or comments have been written to a data set then a message will appear above the data set on the Model Data Screen. They are defined based on a series of tests that are made on the data throughout the program.

The tests and associated comments are described in the following table.

Criteria	Comments
The time duration of a data Set is greater than the time necessary for the model to move half its length but less than its whole length	Short Data Set
The set is longer than 5 seconds and has an average speed lower than 0.001 m/sec	Zeros
The Set is less than the time necessary for the model to move half its length and is longer than ten seconds	Low Speed Data Set
If cursers are moved in the Model Test Data / View screen.	Left (or Right) cursor has been moved

4.4.6 Raw Data Graphics Screen

Although the data sets are calculated automatically you are given the option to either review the selected data sets or modify them. <SHIFT-F8> activates the graphic screen which displays the time histories of each data channel. Up to four time series channels can be viewed at one time, selected from the upper section of the Model Test Data screen. Figure 12 illustrates the graphic screen with "Resistance" and "Carriage Speed" channels selected. The vertical lines on the plot signify the selected cursor position defining the beginning and end of each set.

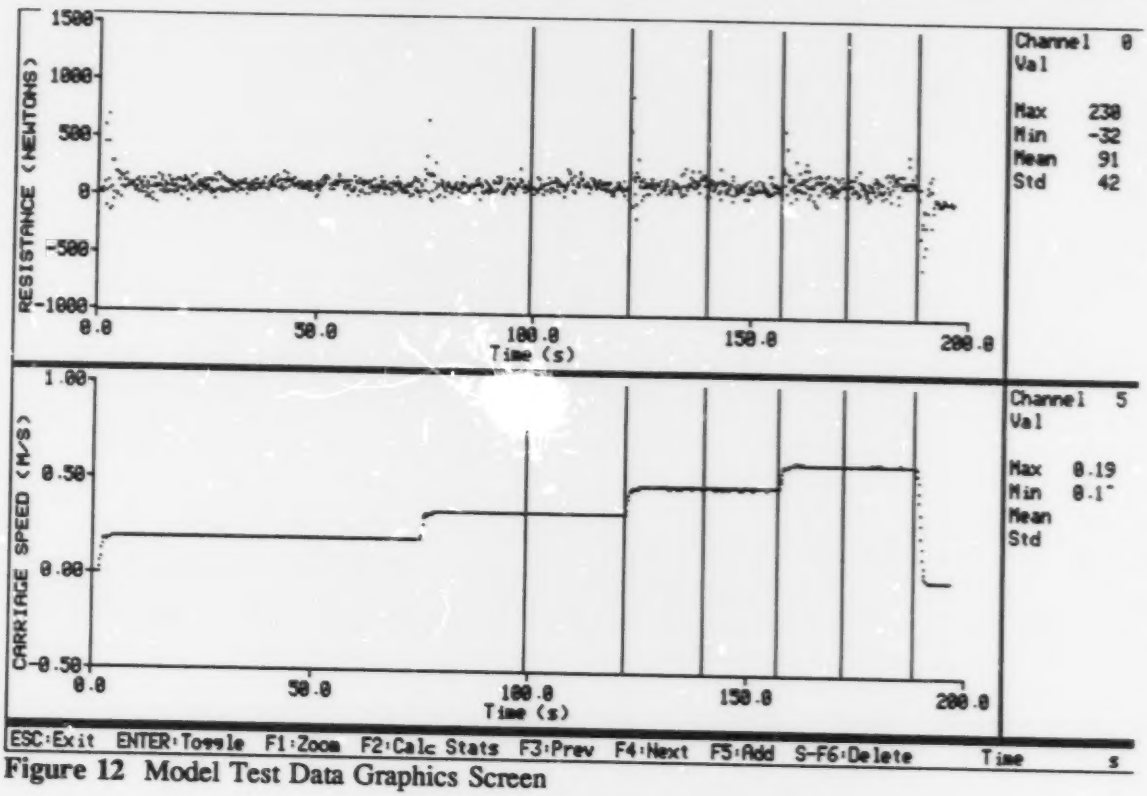

Figure 12 Model Test Data Graphics Screen

You can edit the cursor positions using the <ENTER> and function keys. The "current" cursor set is identified with a different colour and dotted line. <F3> and <F4> moves the current cursor to either the previous or next cursor position. The location of either cursor can be adjusted using the <CURSOR LEFT> and <CURSOR RIGHT> keys. Toggle between the two cursers using the <ENTER> key. To zoom into any area of data press the <F1> function key and two additional cursers will be displayed. Position these using the <CURSOR LEFT> and <CURSOR RIGHT> keys and press <F1> again. The time series data will be re-plotted to the new area.

NOTE: After zooming you will not be permitted to move or select cursers that do not appear on the screen.

Cursers may be added or deleted using the <F5> and <SHIFT-F6> keys respectively.

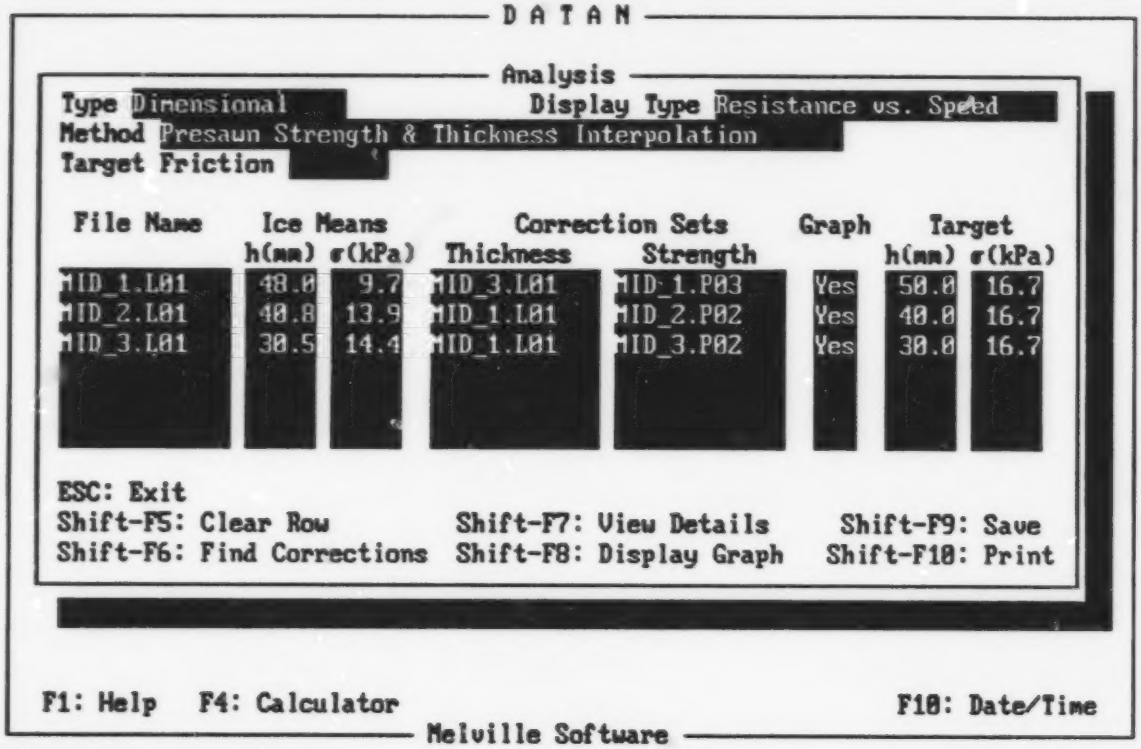

Figure 13 Analysis Screen

4.5 Analysis Screen

The Analysis Screen, Figure 13 permits you to normalize the results from the model tests with respect to ice thickness and strength using a number of different techniques.

NOTE: A detailed description of each analysis procedure is described in ANNEX A.

The Analysis screen has two subordinate screens. A graphic screen, <SHIFT-F8>, displays x-y plots of the original data and the corrected data, based on the target strength and thicknesses that you have selected. The second subordinate screen <SHIFT-F7> displays the speed, resistance, thickness and strength of the data set under analysis.

The screen is divided into two sections. The upper section contains data pertinent to the overall analysis procedure. The lower section contains a table used to define the data correction procedure.

NOTE: The selection of Analysis "Type" and "Method" in the upper screen section will impact on the list contents and display in the rest of the screen.

The upper section of the Analysis screen has a number of field options.

Type	The type of analysis required, this can be a non-dimensional or dimensional analysis.
Method	The method adopted for the analysis. The list of options will depend on the Type selected.
Display Type	The type of x-y plot used in the graphical display of the corrected and uncorrected data. The list of options will depend on the Type and Method selected.
Target Friction	Used during either the dimensional correction for friction or the non-dimensional Colbourne friction method.

The lower section of the screen is used to select the test that you want to correct and the associated tests that will be used. For example in the case of conventional level ice and presawn tests it will allow you to select which presawn test is used to correct the level ice test. In the case of a non-dimensional analysis it will allow you to group the selected test with a series of other tests.

There are six function keys:

<SHIFT-F5>	Clears a row of data from the table.
<SHIFT-F6>	Calculates the corrections based on the selected procedures.

<SHIFT-F7>	Activates the View Window which will display the raw data values for the test associated with the current cursor position.
<SHIFT-F8>	Activates graphics display selected in "Display Type".
<SHIFT-F9>	Saves the corrected data to a file.
<SHIFT-F10>	Plots the graphics display selected in "Display Type" to a file.

NOTE: Before you exit this screen it is important that you save each file set. These are then used in the "Comparison Screen".

4.5.1 Type Selection - Non-Dimensional Analysis

There are three options in the non-dimensional list, Colbourne, Colbourne Friction and a general non-dimensional form. Selecting Colbourne will give three Display Type options:

- Resistance vs Speed.
- Non-Dimensional Breaking Resistance vs Ice Thickness Froude Number.
- Non-Dimensional Clearing Resistance vs Ice Thickness Froude Number.

Selecting the other non-dimensional group or Colbourne Friction will give one Display Type option, Resistance vs Speed.

Once the Type, Method and Display Type are selected move to the left hand column of the table under "File Name".

All the non-dimensional analysis types use a method that groups sets of tests together that use the same model but have different ice properties. Once grouped, the data is normalized using some variable or group of variables and the resistance values derived at the target ice properties by taking the product of the normalized group and the target values. There is no differentiation between corrections for ice thickness and strength. First enter the test you wish to analyze by pressing <ENTER> in the left column of the table under "File Name". This will activate the file

entry window. Select the file you wish to analyze and move to the columns under "Correction Sets" and select the tests that you want to use to correct the subject test. In the case of the Colbourne analysis you must select pre-sawn and level ice tests. You may select as many different tests as you want but must select at least one pre-sawn and one level ice test. In the case of the other non-dimensional analysis methods you may select as many level ice tests as you want. Pre-sawn tests are not required in the analysis and will not be used.

The next option is to select which graphs you want plotted. Move the cursor to the column under "Graph" and press <ENTER>, a pop-up list will give you the option of either "Yes" or "No". The last two columns allow you to input the target ice strength and thickness for the analysis.

4.5.2 Type Selection - Dimensional Analysis

The dimensional analysis is based on correcting the data with existing tests conducted at different ice thicknesses and strengths. Two conventional corrections are commonly used, the strength correction based on pre-sawn tests and the thickness correction based on tests in two different ice thicknesses.

After selecting Dimensional in the "Type" window the "Method" window will display a series of options:

- No Strength & No Thickness Correction
- Presawn Strength & No Thickness Correction
- No Strength & Thickness Interpolation
- Presawn Strength & Thickness Interpolation
- $dR/d\sigma$ & No Thickness Correction
- No Strength Correction & dR/dh
- Presawn Strength & dR/dh

Selecting one of these options will define the type of analysis conducted on the data.

The options in the Display Type list are:

- Resistance vs Speed
- Resistance vs Strength
- Resistance vs Thickness

Selecting one of these options will define how the data is displayed in the graphics subordinate screen.

Move to the first column in the table and press <ENTER>. Select the file you want to analyze with the pop-up window and move to the "Correction Sets" column. There are two columns, one for the test associated with the strength correction and one for the thickness correction. Depending on the selected correction procedure you will need to enter different test files. In the case of the "Pre-sawn Strength and Thickness Interpolation" enter the pre-sawn test associated with the level ice test under the strength column and a level ice test, with a significantly different ice thickness, under the thickness column.

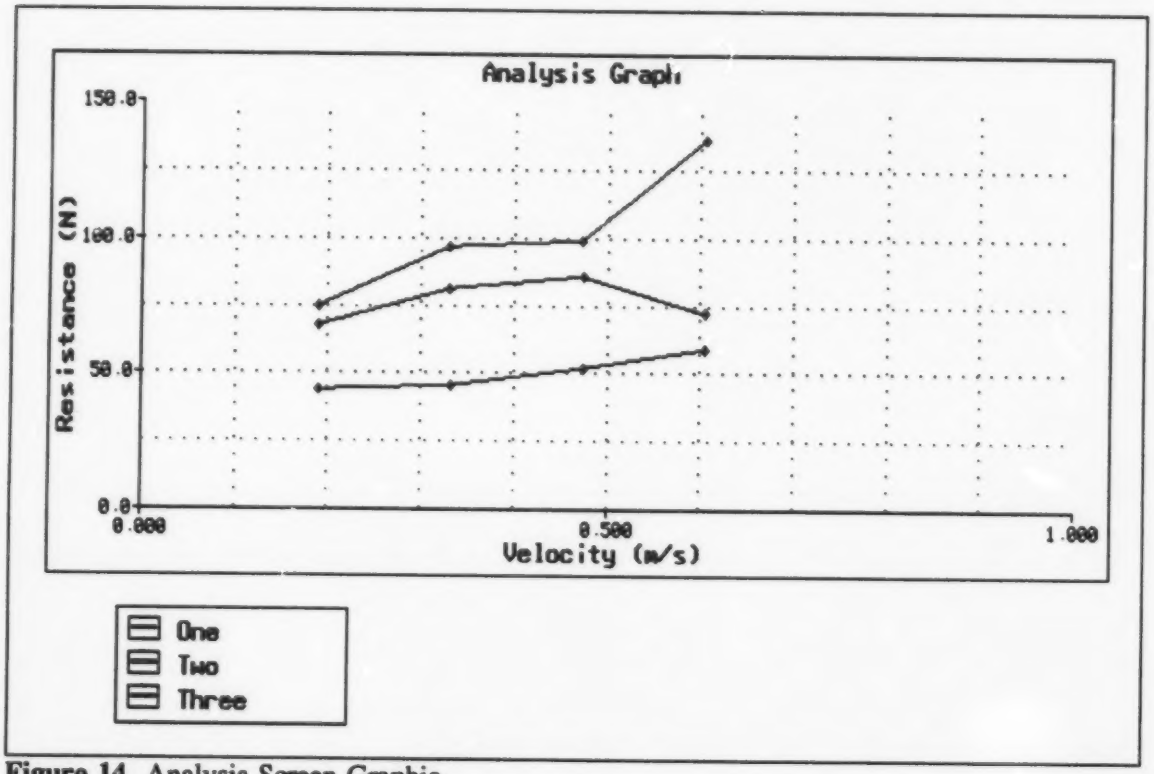

Figure 14 Analysis Screen Graphic

Once the files have been selected and corrected you can view the data by pressing <SHIFT-F8> as illustrated in Figure 14. Each data point will be connected with a straight line.

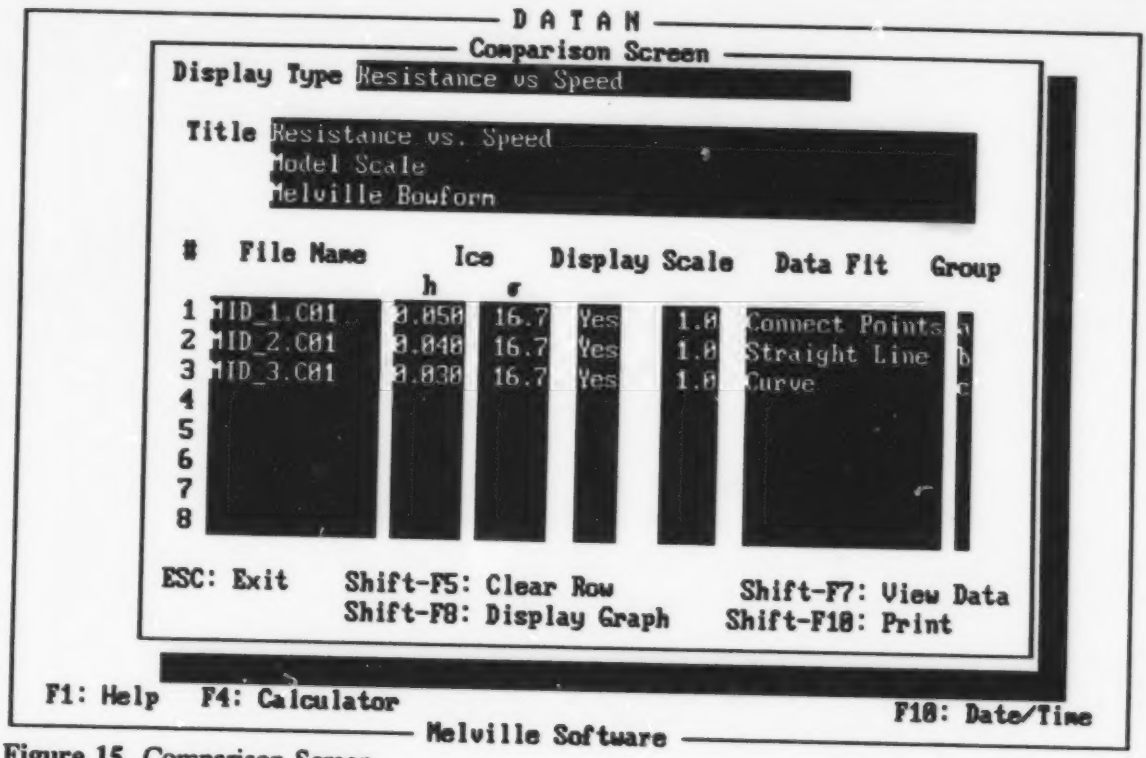

Figure 15 Comparison Screen

4.6 Comparison Screen

The comparison screen, Figure 15, allows you to present the analyzed data and compare it with other tests programs. The screen consists of a number of variable fields.

Title — The Title of the figure which will be used in the printed hard copy of the data.

Display Type — The Form of Display. This can be selected from a number of options;

Resistance vs Speed
Resistance vs Ice Thickness
Resistance vs Speed & OW and Thrust
Speed vs Ice Thickness
Resistance vs Length

Resistance vs Beam
Resistance vs Length/Breadth
Resistance vs Displacement
Resistance vs Friction
Resistance vs Shimanski
Resistance vs Kashteljan

File Name — Selected from the corrected files saved in the Analysis section.

h — Target Ice thickness to which the data file has been corrected.

σ — Target Ice strength to which the data file has been corrected.

Display — Selection to display the data or not.

Scale — Selected Scale. A scale of unity will return the model scale values.

Data Fit — You can select from three different line types, Connected points, a least squares straight line through the data or a least squares second order polynomial through the data.

Group — Depending on the type of display, you will want the data grouped in different ways. The "Grouping" instructs the program which data sets should be aligned together for the display. For example, selecting Resistance vs Speed will require that each test is in a different group, since each test yields resistance data as a function of speed. Selecting Resistance vs Ice Thickness will require that the set of tests with the same model, tested in different ice thicknesses, are in the same group. The program will

automatically select the common speeds amongst the data for plotting.

In addition there are four function keys:

<SHIFT-F5> Clears a row of data from the table.

<SHIFT-F7> Activates the View Window, Figure 16, which will display the corrected values for the test associated with the current cursor position.

<SHIFT-F8> Activates graphics display selected in "Display Type".

<SHIFT-F10> Plots the graph to a file.

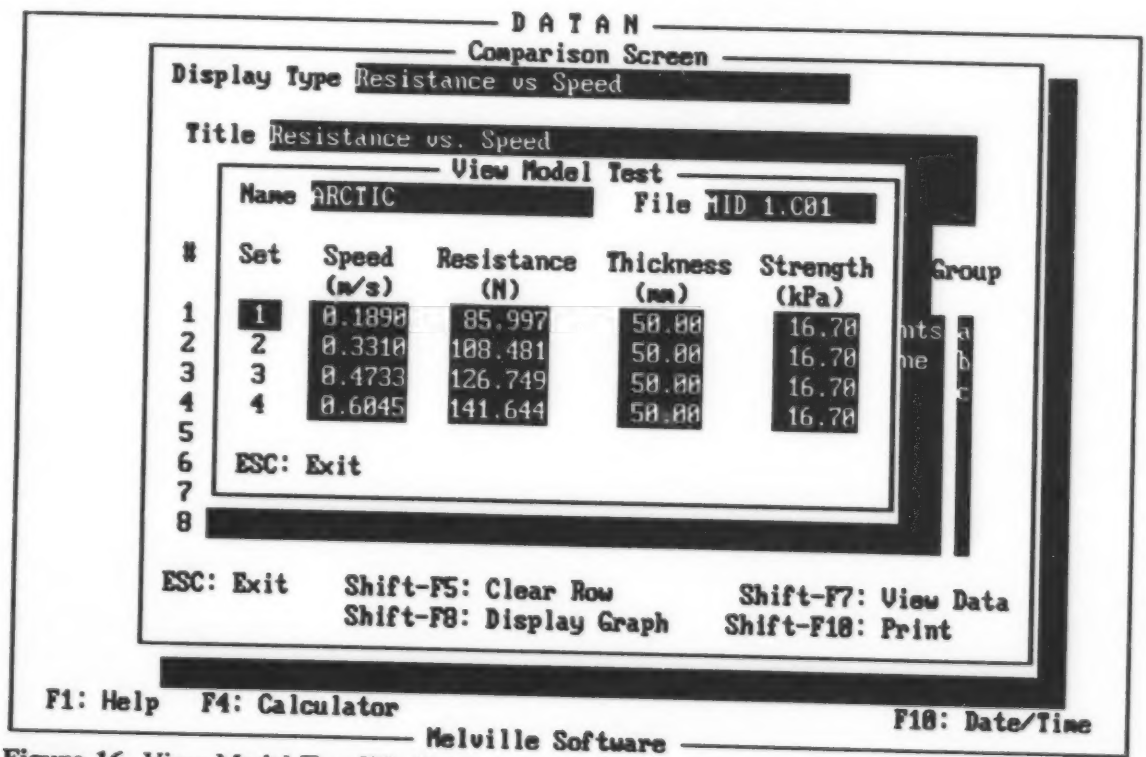

Figure 16 View Model Test Window

Bibliography

Colbourne, B.J. 1989 PhD Thesis; Memorial University of Newfoundland.

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ANNEX A

Analysis Correction Algorithms

A1.0 Analysis Algorithms

A2.0 General

There are a number of algorithms used in the analysis section of the program that have been developed in the literature. The following sections describe each in detail and additional information can be obtained from the original source listed in the bibliography.

A3.0 Non-Dimensional Analysis

A3.1 Colbourne Method

Dr. B. Colbourne (Colbourne 1989) of the Institute of Marine Dynamics in St. John's, Newfoundland has developed a non-dimensional analysis based on the results of the model tests at that facility.

The analysis breaks the total ice breaking resistance into an open water frictional resistance, a Clearing resistance and a Breaking resistance.

The method uses the level ice and pre-sawn tests.

The clearing resistance is calculated by taking the pre-sawn resistance R_{ps} and deducting the frictional resistance R_f.

The Friction resistance, R_f, is defined as:

$$R_f = \tfrac{1}{2}\rho S V^2 C_F \qquad [1]$$

where

ρ	=	Ice Density
S	=	Surface Area of Model
S	=	1.7 x L x D + Δ/D

$$C_F = \frac{0.075}{(\log_{10} Rn - 2)^2}$$

V	=	Ship Speed
L	=	Ship Length
D	=	Ship Draft
Δ	=	Ship Displacement

Rn	=	Reynold's Number
Rn	=	VL/υ
υ	=	Kinematic Viscosity (m^2/sec)

The clearing Resistance R_c is defined as;

$$R_c = R_{ps} - R_f \qquad [2]$$

It is then assumed that the clearing resistance can be expressed in the following non-dimensional form:

$$\log_{10}\left(\frac{R_c}{\rho BhV^2}\right) = \log_{10}C_c + n1 \cdot \log_{10}\left(\frac{V}{\sqrt{gh}}\right) \qquad [3]$$

where

C_c	=	Clearing Resistance Coefficient
ρ	=	Ice Density
B	=	Model Beam
h	=	Ice Thickness
n1	=	Clearing Resistance Index
V	=	Test Speed

A least squares regression is used to calculate values of C and n1 for each test we are correcting. This gives:

$$R_c = C_c \rho BhV^2\left(\frac{V}{\sqrt{gh}}\right)^{n1} \qquad [4]$$

The Breaking component of resistance is then calculated from;

$$R_b = R_T - R_c - R_f \qquad [5]$$

where

R_T	=	Level Ice resistance
R_c	=	Clearing resistance
R_f	=	Friction Resistance

NOTE: The Clearing Resistance used to calculate R_b is taken from the regression line using the derived values of C_c and n1 at the values of ice strength and thickness corresponding to the level ice test using [4].

It is then assumed that the breaking resistance can be expressed in the following non-dimensional form:

$$\log_{10}\left(\frac{R_b}{\rho B h V^2}\right) = \log_{10} B_c + n2 \cdot \log_{10}\left(\frac{V}{\sqrt{\sigma/\rho}}\right) \qquad [6]$$

where

σ	=	Ice Flexural Strength
B_c	=	Breaking Resistance Coefficient
n2	=	Breaking Resistance Index

A least squares regression is used to calculate the values of B_c and n2, giving:

$$R_b = B_c \rho B h V^2 \left(\frac{V}{\sqrt{\sigma/\rho}}\right)^{n2} \qquad [7]$$

The total resistance is calculated by adding the calculated Clearing [4], Breaking [7] and Frictional [1] resistances together, for each desired strength or thickness variable.

A3.2 Colbourne Friction Method

Dr. B. Colbourne has also developed a relationship between the hull friction coefficient and the two resistance coefficients B_c and C_c.

$$B_c = K_b \mu B \quad [8]$$

$$C_c = K_c \mu C \quad [9]$$

A least squares regression is used to calculate the values of K_b and B using the values of μ and B_c obtained from the Colbourne Method. Values for K_c and C are calculated using μ and C_c.

Using [8] and [9], new values for B_c and C_c are calculated using the Target Friction Value.

These values are substituted into [4] and [7]. The total resistance is now calculated by adding the clearing, breaking and frictional resistances together.

A3.3 σh^2 vs Froude Thickness

This analysis uses the level ice tests only. Froude resistance is defined as:

$$R = C \frac{v \sigma h^2}{\sqrt{gh}} \quad [10]$$

where

v	=	test speed
σ	=	ice flexural strength
h	=	ice thickness
g	=	gravitational constant
C	=	Froude coefficient

A least squares regression is used to calculate a value for C based on the test data.

The corrected resistance is then calculated using [10] with h = desired thickness and σ = desired strength.

A4.0 Dimensional Methods

A4.1 Linear Presawn Strength Correction

This correction method requires one level ice test and one presawn test and will perform a linear correction for differences in target and measured ice strengths.

For each matching speed in the level ice test and "correcting" presawn ice test, resistance is plotted against strength, and a least squares line is drawn through the points. The strength for the presawn test is assumed to be zero.

If a speed in the level ice test does not match any in the presawn test, then the average of the other slopes is used.

Each line is now represented as:

$$R = m\sigma + b$$

where

m	=	calculated slope
σ	=	ice strength
b	=	calculated offset

The change in resistance ΔR is

$$\Delta R = (m\sigma_t + b) - R_m$$

where

σ_t	=	target strength
R_m	=	measured resistance

A4.2 dR/dσ

This correction method requires one level ice test and will adjust the model resistance for differences between target and measured ice strengths. You are required to input the value for dR/dσ.

The change in resistance ΔR is

$$\Delta R_s = \frac{dR}{d\sigma}(\sigma_t - \sigma_m)$$

where

dR/dσ	=	correction ratio
σ_t	=	target strength
σ_m	=	measured strength

A4.3 Thickness Interpolation

This method requires two level ice tests and will perform a linear correction for different ice thicknesses.

For each matching speed in the base and correcting test, resistance is plotted against thickness and a least squares line is drawn through the points.

If a speed in the base set does not match any in the correcting test, then the average of the other slopes is used.

Each line is now represented as:

$$R = mh + b$$

where

m	=	calculated slope
h	=	ice thickness
b	=	calculated offset

The change in resistance ΔR is:

$$\Delta R = (mh_t + b) - R_m$$

where

h_t	=	target thickness
R_m	=	measured resistance

A4.4 dR/dh

This correction method requires one level ice test and will adjust the model resistance for differences between target and measured thickness. You are required to input dR/dh.

The change in resistance ΔR is:

$$\Delta R = \frac{dR}{dh}(h_t - h_m)$$

where

dR/dh	=	value to correct by
h_t	=	target thickness
h_m	=	measured thickness

A4.5 Exponential Friction Correction

This method requires one level or presawn ice test and will correct for differences in target and measured hull frictions.

It is assumed that the hull resistance vs friction line is in the form:

$$R = ae^{b\log\mu}$$

where

R	=	resistance
μ	=	friction coefficient
a,b	=	constants to be determined as a functioning speed

Using existing test series and least squares regression analysis, different values of 'a' and 'b' are calculated for each speed. Selecting this option you will be required to input values for 'a' and 'b' at two different speeds.

Based on these input values the computer calculates the associated Resistance at the test friction coefficient and target friction coefficient. It is then assumed that the ratio of the calculated resistance values will be the same as the ratio of the target and actual resistance values from the test. Therefore:

$$\Delta R_F = \frac{R_2 - R_M}{R_1} - R_M$$

where

ΔR_f	=	friction resistance correction
R_M	=	measured resistance
R_1	=	calculated resistance at target friction coefficient

R_2 = calculated resistance at measured friction coefficient

For speeds other than those input to the friction correction screen, the program calculates a linear interpolation of R_1 and R_2.

APPENDIX 2

Matrix of Model Tests used in the DATAN Analysis

The following tables represent the model tests used in the analysis. The tables are divided by model and test. Each table is divivded into 11 columns:

Column 1; Directory

The location of the files. This is a directory under DATAN in which the data files are located. For example, the KALVIK model tests are in the directory C:\DATAN\KALVIK

Column 2; File Name

The name of the file in which the raw data time series is stored. These are descriptive of the individual test but limited to eight characters. As a result, abreviations are used to describe individual tests.

Column 3; Date

The date of the test

Column 4; Model

The generic model used in the test and a description of its bow form or dimensions as appropriate.

Column 5; Scale

The model scale of the test.

Column 6 & 7; Length and Beam

The full scale length and beam of the ship represented as the model.

Column 8; Type

The type of test. This may either be a presawn or level ice test.

Column 9 & 10; Ice thickness and Strength

The target ice thicknesses and strength for the tests. These are not the actual ice thicknesses and strengths recorded during the tests.

Column 11; Comments

Relavent comments or information about each test.

Table 1
ICE RESISTANCE DATA FILES
MV ARCTIC Friction Test Series

DIRECTORY	FILE NAME	DATE D/M/YR	MODEL	SCALE	LENGTH [m]	BEAM [m]	TYPE	h_i [mm]	σ_i [kPa]	COMMENTS
BBBLMB	FRIC1.D01	02/12/86	ARCTIC	30	206	23	LEVEL ICE	40	19	FRICTION TEST BOW = 0.06 MIDBODY = 0.06
BBBLMB	FRIC2.D01	04/12/86	ARCTIC	30	206	23	LEVEL ICE	50	19	FRICTON TEST BOW = 0.06 MIDBODY = 0.06
BBBLMB	FRIC3.D01	18/12/86	ARCTIC	30	206	23	LEVEL ICE	50	17	FRICTION TEST BOW = 0.06 MIDBODY = 0.06
	FRIC3.D02						PRESAWN	50	-	
BBBLMB	FRIC4.D01	23/12/86	ARCTIC	30	206	23	LEVEL ICE	50	17	FRICTION TEST BOW = 0.004 MIDBODY = 0.06 JAMMED AT 54m
	FRIC4.D02						PRESAWN	50	-	
BBBLMB	FRIC5.D01	21/01/87	ARCTIC	30	206	23	LEVEL ICE	50	19	FRICTION TEST BOW = 0.06 MIDBODY = 0.06
	FRIC5.D02						PRESAWN	50	-	
BBBLMB	FRIC6.D01	27/01/87	ARCTIC	30	206	23	LEVEL ICE	50	19	FRICTION TESTS BOW = 0.004 MIDBODY = 0.004
	FRIC6.D02						PRESAWN	50	-	
BBBLMB	FRIC7.D01	30/01/87	ARCTIC	30	206	23	LEVEL ICE	50	19	FRICTION TESTS BOW = 0.06 MIDBODY = 0.004
	FRIC7.D02						PRESAWN	50	-	

BBBLMB = Base Beam : Base Length : Melville Bow

APPENDIX 2

Table 2
ICE RESISTANCE DATA FILES
MV ARCTIC Friction Test Series

DIRECTORY	FILE NAME	DATE D/M/YR	MODEL	SCALE	LENGTH [m]	BEAM [m]	TYPE	h_i [mm]	σ_i [kPa]	COMMENTS
BBBLMB	FRIC8.D01	03/02/87	ARCTIC	30	206	23	LEVEL ICE	50	19	FRICTION TESTS BOW = 0.06 MIDBODY = 0.004
	FRIC8.D02						PRESAWN	50	-	
BBBLMB	FRIC9.D01	06/02/87	ARCTIC	30	206	23	LEVEL ICE	50	19	FRICTION TEST BOW = 0.06 MIDBODY = 0.06
	FRIC9.D02						PRESAWN	50	-	
BBBLMB	FRIC10.D03	10/02/87	ARCTIC	30	206	23	LEVEL ICE	50	19	FRICTION TEST BOW = 0.004 MIDBODY = 0.06
	FRIC10.D04						PRESAWN	50	-	
BBBLMB	FRIC11.D05	12/02/87	ARCTIC	30	206	23	LEVEL ICE	50	19	FRICTION TEST BOW = 0.06 MIDBODY = 0.06
	FRIC11.D06						PRESAWN	50	-	
BBBLMB	FRIC12.D01	06/10/87	ARCTIC	30	206	23	LEVEL ICE	50	19	FRICTION TEST BOW = 0.06 MIDBODY = 0.06
	FRIC12.D02						PRESAWN	50	-	
BBBLMB	FRIC13.D01	08/10/87	ARCTIC	30	206	23	LEVEL ICE	50	19	FRICTION TEST BOW =0.33 MIDBODY = 0.06
	FRIC13.D02						PRESAWN	50	-	

BBBLMB = Base Beam : Base Length : Melville Bow

Table 3
ICE RESISTANCE DATA FILES
MV ARCTIC Midbody Length Variation Series

DIRECTORY	FILE NAME	DATE D/M/Y	MODEL	SCALE	LENGTH [m]	BEAM [m]	TYPE	h_i [mm]	σ_f [kPa]	COMMENT
BBBLMB	MID_1.D01	19/01/88	ARCTIC	30	206	23	LEVEL ICE	50	19	MELVILLE BOW BOW μ = 0.06 MID μ = 0.06
	MID_1.D03						PRESAWN	50	-	
BBBLMB	MID_2.D01	21/01/88	ARCTIC	30	206	23	LEVEL ICE	40	19	MELVILLE BOW BOW μ = 0.06 MID μ = 0.06
	MID_2.D02						PRESAWN	40	-	
BBBLMB	MID_3.DO1	22/01/88	ARCTIC	30	206	23	LEVEL ICE	30	19	MELVILLE BOW BOW μ = 0.06 MID μ = 0.06
	MID_3.DO2						PRESAWN	30	-	
BBBLMB	MID_4HF.DO1	26/01/88	ARCTIC	30	206	23	LEVEL ICE	50	19	MELVILLE BOW BOW μ = 0.33 MID μ = 0.33
	MID_4HF.D02						PRESAWN	50	-	
	MID_4HF.D03						PRESAWN	50	-	
BBSLMB	MID_5MF.DO1	28/01/88	INTERM EDIATE ARCTIC	30	134	23	LEVEL ICE	30	19	MELVILLE BOW BOW μ = 0.33
	MID_5MF.D02						PRESAWN	30	-	
BBSLOB	MID_6MF.DO1	29/01/88	SHORT ARCTIC	30	124	23	LEVEL ICE	30	19	ORIGINAL BOW BOW μ = 0.33
	MID_6MF.DO2						PRESAWN	30	-	
BBSLMB	MID_7.D01	02/02/88	SHORT ARCTIC	30	134	23	LEVEL ICE	30	19	MELVILLE BOW BOW μ = 0.06
	MID_7.D02						PRESAWN	30		
BBSLMB	MID_8LF.D01	03/02/88	SHORT ARCTIC	30	134	23	LEVEL ICE	30	19	MELVILLE BOW BOW μ = 0.004
	MID_8LF.D02						PRESAWN	30		
BBSLOB	MID_9LF.DO1	04/02/88	SHORT ARCTIC	30	134	23	LEVEL ICE	30	19	ORIGINAL BOW BOW μ = 0.004
	MID_9LF.DO2						PRESAWN	30		

BBBLMB = Base Beam : Base Length : Melville Bow
BBSLMB = Base Beam : Short Length : Melville Bow
BBSLOB = Base Beam : Short Length : Original Bow

Table 4
ICE RESISTANCE DATA FILES
MV ARCTIC Midbody Length Variation Series

DIRECTORY	FILE NAME	DATE D/M/Y	MODEL	SCALE	LENGTH [m]	BEAM [m]	TYPE	h_i [mm]	σ_i [kPa]	COMMENTS
BBSLOB	MID_10.DO1	05/02/88	SHORT ARCTIC	30	124	23	LEVEL ICE	30	19	ORIGINAL BOW BOW μ = 0.06
	MID_10.D02						PRESAWN	30	-	
BBBLOB	MID_11.D01	09/02/88	ARCTIC	30	197	23	LEVEL ICE	30	19	ORIGINAL BOW BOW μ = 0.06 MID μ = 0.06
	MID_11.DO2						PRESAWN	30	-	
BBLLOB	MID_12.D01	10/02/88	LONG ARCTIC	30	248	23	LEVEL ICE	30	19	ORIGINAL BOW BOW μ = 0.06 MID μ = 0.06
	MID_12.DO2						PRESAWN	30	-	
BBLLMB	MID_13.DO1	11/02/88	LONG ARCTIC	30	258	23	LEVEL ICE	30	19	MELVILLE BOW BOW μ = 0.06 MID μ = 0.06
	MID_13.DO2			30			PRESAWN	30	-	
BBILMB	MID_14.D01	12/02/88	INTERMEDIATE ARCTIC	30	172	23	LEVEL ICE	30	19	MELVILLE BOW BOW μ = 0.06 MID μ = 0.06
	MID_14.D02			30			PRESAWN	30	-	

BBSLOB = Base Beam : Short Length : Original Bow
BBLLOB = Base Beam : Long Length : Original Bow
BBILMB = Base Beam : Intermediate Length : Melville Bow
BBLLMB = Base Beam : Long Length : Melville Bow

Table 5
ICE RESISTANCE DATA FILES
MV ARCTIC Beam Variation Series

DIRECTORY	FILE NAME	DATE D/M/Y	MODEL	SCALE	LENGTH [m]	BEAM [m]	TYPE	h_i [mm]	σ_i [kPa]	COMMENTS
BBBLMB	BEAM1.DO1	06/06/89	ARCTIC	30	206	23	LEVEL ICE	30	25	BEAM TESTS BASE BEAM BASE MIDBODY
	BEAM1.DO2						PRESAWN	30	-	
NBBLMB	BEAM2.DO1	07/06/89	NARROW ARCTIC	30	206	18	LEVEL ICE	30	25	BEAM TESTS DECREASED BEAM BASE MIDBODY
	BEAM2.DO2						PRESAWN	30	-	
NBILMB	BEAM3.DO1	08/06/89	NARROW, INTERMEDIATE LENGTH ARCTIC	30	165	18	LEVEL ICE	30	25	BEAM TESTS DECREASED BEAM INTERMEDIATE MIDBODY
	BEAM3.DO2						PRESAWN	30	-	
NBSLMB	BEAM4.DO1	09/06/89	ARCTIC NARROW, SHORT	30	138	18	LEVEL ICE	30	25	BEAM TESTS DECREASED BEAM SHORT MIDBODY
	BEAM4.DO2						PRESAWN	30	-	
BBBLMB	BEAM5.DO1	13/06/89	ARCTIC	30	206	23	LEVEL ICE	40	25	BEAM TESTS BASE BEAM BASE MIDBODY
	BEAM5.DO2						PRESAWN	40	-	
BBLLMB	BEAM6.DO1	14/06/89	LONG ARCTIC	30	258	23	LEVEL ICE	30	25	BEAM TESTS BASE BEAM LONG MIDBODY
	BEAM6.DO2						PRESAWN	30	-	
WBBLMB	BEAM7.D01	15/06/89	WIDE ARCTIC	30	206	27	LEVEL ICE	30	25	BEAM TESTS INCREASED BEAM BASE MIDBODY
	BEAM7.DO2						PRESAWN	30	-	
WBSLMB	BEAM8.DO1	16/06/89	WIDE, SHORT ARCTIC	30	160	27	LEVEL ICE	30	25	BASE TESTS INCREASED BEAM SHORT MIDBODY
	BEAM8.DO2						PRESAWN			

BBBLMB = Base Beam : Base Length : Melville Bow
NBBLMB = Narrow Beam : Base Length : Melville Bow
NBILMB = Narrow Beam : Intermediate Length : Melville Bow
NBSLMB = Narrow Beam : Short Length : Melville Bow
BBLLMB = Base Beam : Long Length : Melville Bow
WBBLMB = Wide Beam : Base Length : Melville Bow
WBSLMB = Wide Beam : Short Length : Melville Bow

Table 6
ICE RESISTANCE DATA FILES
Louis S St Laurent

DIRECTORY	FILE NAME	DATE D/M/Y	MODEL	SCALE	LENGTH [m]	BEAM [m]	TYPE	h_i [mm]	σ_i [kPa]	COMMENTS
LOUISO	LOUIS1.D01	28/10/86	ORIG LOUIS	15	101.8	24.36	LEVEL ICE	67	30	
	LOUIS1.D02						PRESAWN	67	-	ICE CRUSHING AT SHOULDER
	LOUIS1.D03						PRESAWN	67	-	SOME CHANNEL SPREADING
LOUISO	LOUIS2.D01	30/10/86	ORIG LOUIS	15	101.8	24.36	LEVEL ICE	47	30	
	LOUIS2.D02						PRESAWN	47	-	V = 0.515
	LOUIS2.D03						PRESAWN	47	-	V = 0.258, .774
LOUISO	LOUIS3.D01	03/11/86	ORIG LOUIS	15	101.8	24.36	LEVEL ICE	100	30	
	LOUIS3.D02						PRESAWN	100	-	V = 0.515
	LOUIS3.D03						PRESAWN	100	-	V = 0.258, .774
LOUISM	LOUIS4.DO1	07/11/86	MELVILLE BOW	15	106.68	24.36	LEVEL ICE	100	20	
	LOUIS4.D02						PRESAWN	100	-	V = 0.515
	LOUIS4.D03						PRESAWN	100	-	V = 0.515
	LOUIS4.D04						PRESAWN	100	-	V = .258, .773
LOUISM	LOUIS5.D01	10/11/86	MELVILLE BOW	15	106.68	24.36	LEVEL ICE	67	20	FAN FAILURE DURING TEST
	LOUIS5.D02						PRESAWN	67	-	
	LOUIS5.D03						PRESAWN	67	-	
LOUISM	LOUIS6.D01	12/11/86	MELVILLE BOW	15	106.68	24.36	LEVEL ICE	67	30	
	LOUIS6.D03						PRESAWN	-	-	V = .516 REANALYSED DUE TO HARD SPOT
	LOUIS6.D04						LEVEL ICE	67	20	CREEPING SPEED V=0.01
	LOUIS6.D05						PRESAWN	67	-	

LOUISO = Louis S St Laurent with the Original Bow
LOUISM = Louis S St Laurent with the Melville Bow

Table 7
ICE RESISTANCE DATA FILES
Louis S St Laurent

DIRECTORY	FILE NAME	DATE D/M/Y	MODEL	SCALE	LENGTH [m]	BEAM [m]	TYPE	h_i [mm]	σ_i [kPa]	COMMENTS
LOUISM	LOUIS7.D01	14/11/86	MELVILLE BOW	15	106.68	24.36	LEVEL ICE	47	30	
	LOUIS7.D03						PRESAWN	47	-	V = .516
	LOUIS7.D04						PRESAWN	47	-	V = .258, .774
LOUISR	LOUIS8.D01	18/11/86	R-CLASS BOW	15	106.68	24.29	LEVEL ICE	100	30	
	LOUIS8.D03						PRESAWN	100	-	V = .516
	LOUIS8.D04						PRESAWN	100	-	V = .258, .774, .516
LOUISR	LOUIS9.D01	24/11/86	R-CLASS BOW	15	106.68	24.29	LEVEL ICE	67	20	
	LOUIS9.D02						PRESAWN	67	-	V = .516
	LOUIS9.D03						PRESAWN	67	-	V = .258, .774, .516
LOUISR	LOUIS10.D01	26/11/86	R-CLASS BOW	15	106.68	24.29	LEVEL ICE	67	30	
	LOUIS10.D03						PRESAWN	67	-	V = 0.516
	LOUIS10.D04						PRESAWN	67	-	V = .258, .774, .516
LOUISR	LOUIS11.D01	28/11/86	R-CLASS BOW	15	106.68	24.29	LEVEL ICE	47	30	
	LOUIS11.D02						PRESAWN	47	-	V = .516
	LOUIS11.D03						PRESAWN	47	-	V = .258, .774, .516

LOUISR = Louis S St Laurent with the R-Class Bow
LOUISM = Louis S St Laurent with the Melville Bow

APPENDIX 2

Table 8
ICE RESISTANCE DATA FILES
Bernier

DIRECTORY	FILE NAME	DATE	MODEL	SCALE	LENGTH [m]	BEAM [m]	TYPE	h_i [mm]	σ_i [mm]	COMMENTS
BERNO	BERNO1.DO1	11/09/90	ORIGINAL BERNIER	15	64.2	14.94	LEVEL ICE	40	60	
	BERNO1.D02						PRESAWN	40	-	
	BERNO1.D03						LEVEL ICE	40	40	
BERNO	BERNO2.D01	11/09/90	ORIGINAL BERNIER	15	64.2	14.94	LEVEL ICE	20	50	
	BERNO2.D03						PRESAWN	20	-	
	BERNO2.D05						LEVEL ICE	20	20	
BERNB	BERNB1.D03	17/09/90	BEAUFORT BERNIER	15	64.62	14.94	PRESAWN	40	-	
	BERNB1.DO4						LEVEL ICE	40	40	
BERNB	BERNB2.D01	19/09/90	BEAUFORT BERNIER	15	64.62	14.94	LEVEL ICE	60	60	
	BERNB2.D04						PRESAWN	60	-	
	BERNB2.D05						LEVEL ICE	60	40	
BERNB	BERNB3.D01	20/09/90	BEAUFORT BERNIER	15	64.62	14.94	LEVEL ICE	20	60	
	BERNB3.D04						PRESAWN	20	-	
	BERNB3.D05						LEVEL ICE	20	40	

BERNO = Original Bow on the CCG Bernier
BERNB = Beaufort Sea Bow on the CCG Bernier

Table 9
ICE RESISTANCE DATA FILES
Bernier

DIRECTORY	FILE NAME	DATE	MODEL	SCALE	LENGTH [m]	BEAM [m]	TYPE	h_i [mm]	σ_i [mm]	COMMENTS #
BERNR	BERNR1.D02	05/10/90	R-CLASS BERNIER	15	64.62	14.94	LEVEL ICE	60	60	
	BERNR1.D05						LEVEL ICE	60	60	
BERNR	BERNR2.D01	10/10/90	R-CLASS BERNIER	15	64.62	14.94	LEVEL ICE	40	60	
	BERNR2.D04						PRESAWN	40	-	
	BERNR2.D05						LEVEL ICE	40	60	
BERNR	BERNR3.D01	11/10/90	R-CLASS BERNIER	15	64.62	14.94	LEVEL ICE	20	60	
	BERNR3.D04						PRESAWN	20	-	
	BERNR3.D05						LEVEL ICE	20	60	

Table 10
ICE RESISTANCE DATA FILES
Kigoriak

DIRECTORY	FILE NAME	DATE D/M/Y	MODEL	SCALE	LENGTH [m]	BEAM [m]	TYPE	h_i [mm]	σ_f [kPa]	COMMENTS
KIGORIAK	KIGOR1.DO1	29/03/88	KIGORIAK	22.5	79.3	19.3	LEVEL ICE	29	27	ONE SPEED
	KIGOR1.DO2						LEVEL ICE	29	27	v = 1.0 m/sec
	KIGOR1.DO3						LEVEL ICE	29	27	v = 0.8 m/sec
	KIGOR1.DO4						LEVEL ICE	29	27	v = 0.2 m/sec
	KIGOR1.DO5						LEVEL ICE	29	27	CREEPING SPEED
	KIGOR1.DO6						PRESAWN	29	-	
KIGORIAK	KIGOR2.DO1	31/03/91	KIGORIAK	22.5	79.3	19.3	LEVEL ICE	29	27	
	KIGOR2.DO2						PRESAWN	29	-	
KIGORIAK	KIGOR3.D01	07/04/88	KIGORIAK	22.5	79.3	19.3	LEVEL ICE	80	27	v = 0.2 m/sec
	KIGOR3.DO2						LEVEL ICE	80	27	v = 0.8 m/sec
	KIGOR3.D03						LEVEL ICE	80	27	v = 1.0 m/sec
	KIGOR3.DO4						LEVEL ICE	80	27	v = 0.5 m/sec
	KIGOR3.DO5						LEVEL ICE	80	27	CREEPING
	KIGOR3.DO6						ZEROES	-	-	
	KIGOR3.DO7						PRESAWN	80	-	
KIGORIAK	KIGOR4.DO1	12/04/88	KIGORIAK	22.5	79.3	19.3	LEVEL ICE	53	27	
	KIGOR4.DO2						PRESAWN	53	-	
KIGORIAK	KIGOR5.DO1	14/04/88	KIGORIAK	22.5	79.3	19.3	ZEROES	-	-	
	KIGOR5.DO2						LEVEL ICE	53	15	

Table 11
ICE RESISTANCE DATA FILES
NORMAN MCLEOD ROGERS

DIRECTORY	FILE NAME	DATE D/M/Y	MODEL	SCALE	LENGTH [m]	BEAM [m]	TYPE	h, [mm]	σ, [kPa]	COMMENTS
ROGERSO	ROGERS1.DO2	02/11/88	ORIGINAL ROGERS	20	81.15	19.05	LEVEL ICE	30	25	
	ROGERS1.DO4						PRESAWN	30	-	
ROGERSO	ROGERS2.DO2	04/11/88	ORIGINAL ROGERS	20	81.15	19.05	LEVEL ICE	60	25	
	ROGERS2.DO4						PRESAWN	60	-	
ROGERSR	ROGERS3.DO2	08/11/88	R CLASS ROGERS	20	81.15	19.05	LEVEL ICE	30	25	
	ROGERS3.DO4						PRESAWN	30	-	
ROGERSR	ROGERS4.DO2	10/11/88	R CLASS ROGERS	20	81.15	19.05	LEVEL ICE	60	25	
	ROGERS4.DO4						PRESAWN	60	-	